A

COURSE OF SIX LECTURES

ON THE

CHEMICAL CHANGES OF CARBON.

BY

WILLIAM ODLING, M.B., F.R.S.,

FULLERIAN PROFESSOR OF CHEMISTRY, ROYAL INSTITUTION.

Delivered before a Juvenile Auditory *at the* Royal Institution *of* Great Britain *during the Christmas Holidays of* 1868-69.

Reprinted from THE CHEMICAL NEWS, with Notes

BY

WILLIAM CROOKES, F.R.S., &c.

LONDON:
LONGMANS, GREEN, AND CO.
1869.

LONDON:
PRINTED AT THE CHEMICAL NEWS OFFICE,
BOY COURT, LUDGATE HILL, E.C.

PREFACE.

Few men who have ever devoted themselves to Chemistry, forget their first attendance at a Chemical lecture. The lecturer may not be profoundly learned, or even a brilliant manipulator—he may use hard words, and omit to explain them; he may totally fail in some experiments, and only partially succeed in others—it matters not; to an intelligent and imaginative boy there is a magical charm about the new world thus opened to his mind which time can never efface.

But replace the school-room by the Theatre of the Royal Institution, the amateur or itinerant lecturer by Faraday, the imperfect

apparatus by all the appliances which refined science can suggest; can we then wonder if the impressions so formed exercise a lasting and glorious influence over the mind of the youthful spectator?

Only those who have seen the rapt and delighted gaze of the juvenile audiences, as they followed, with intelligent appreciation, each experiment and explanation of Faraday, can fully appreciate the enormous amount of good which must arise from these lectures.

The worthy successor of Faraday, in his Chair at the Royal Institution, has so far followed in the footsteps of his predecessor, that he has continued to give lectures to the young, and with eminently successful results.

The present series of Lectures on the Chemical Changes of Carbon will be found to contain all that can be said upon the subject capable of being comprehended by a Juvenile Auditory; and being printed as they were taken down *verbatim* by the reporter of

the CHEMICAL NEWS, they possess all the vivacity, as well as originality and clearness of style, which distinguish the eminent Chemist by whom they were delivered.

A remarkable feature in these Lectures is the fact that every term made use of is defined as it occurs, and the oral definition is supplemented by a clear and decisive experimental illustration.

It must not be forgotten that CARBON, in some respects, stands alone among the elements. Its compounds are more numerous than those of any other element, and their history, by the older chemists, was considered to constitute a distinct branch of the science, and called "*Organic Chemistry.*" In the present day, the results of research have been to break down the barriers which were supposed to exist between Organic and Inorganic Chemistry; and it has been found that a vast number of bodies, at one time supposed to be producible only by the agency of animal or vegetable life, can now be formed

by the chemist from absolutely inorganic matter. The result of these discoveries has been that the phrase "Organic Chemistry" is, by the more advanced Chemists, abandoned for the more accurate term, "Chemistry of the Compounds of Carbon."

While reminding our youthful readers that the Chemistry of Carbon includes the chemical history of all animal and vegetable substances, we cannot, we think, offer them better advice than to commence that grand study by a careful perusal of Dr. Odling's Lectures "On the Chemical Changes of Carbon."

W. C.

CONTENTS.

LECTURE I.

MARBLE—LIME—CARBONIC GAS.

LECTURE II.

CARBONIC GAS—AIR—OXIDES.

LECTURE III.

AIR—OXIDES—CARBON OR CHARCOAL.

LECTURE IV.

CARBONIC GAS, OR FIXED AIR.

LECTURE V.

GRAPHITE—DIAMOND—LIQUID AND SOLID CARBONIC GAS.

LECTURE VI.

CARBONIC DISULPHIDE—CARBON—CARBONOUS OXIDE—CARBONIC GAS.

ON THE

CHEMICAL CHANGES

OF

CARBON.

LECTURE I.

MARBLE—LIME—CARBONIC GAS.

THOSE of you who are sitting in the front benches, and your no less youthful fellows whom I see scattered about the theatre, who form my especial audience to-day, have, I suppose, most of you, been very recently acquiring at school much valuable knowledge with regard to words, and numbers, and events; and now in your holiday time, like many generations of schoolboys before you, you come to the Royal Institution to learn a little about *things*—about material objects that can be touched and handled and weighed; and in a little time I think most of you will be surprised to find how very interesting and curious are the properties of even

the most common-place things when intelligently examined, and in particular how very remarkable are the changes which this common and, at first sight, uninteresting looking substance—charcoal—is capable of undergoing and effecting.

Now although it is my intention to talk to you about charcoal or carbon, I do not intend to begin with carbon, but with a very different looking substance—one which you may be inclined to think can have but little connection with charcoal at all, and yet which, as I hope to show you, really has a very intimate connection with it,—I mean the substance I hold in my hand, and which you will at once recognise as a slab of marble.

As we have only some half-dozen hours to talk of the many wonderful changes of this wonderful charcoal, we will put aside all preliminaries, and begin at once with an experimental enquiry into the properties of this white substance, marble, and its relation to that black substance, charcoal. We will submit it to several tests or trials, and see how it behaves under those trials; and, first of all, we will try the effect of a blow upon it. If we take the marble, and hit it rather a sharp blow with a hammer, you will observe

that it very quickly breaks into pieces. Here we have a number of similar pieces of marble that have been broken off in this manner; here we have a jar of broken marble, and here is the same marble in a smaller state of division. Now, if I take some ordinary pieces of marble, and put them into a druggists' mortar, and bring the pestle down upon them, I have the power of reducing them to a powder of any degree of fineness. In this jar we have some marble which has been powdered in this manner; here is some in a rather coarser state; here, again, is some which has been very finely powdered for a special purpose; and by chemical means we can get the marble into a much finer state of division, and we then speak of it as precipitated marble. Well, then, the first thing we learn about marble is, that it is a very brittle substance; that is not a great deal to know, but it is something; and you will find in science that every fact, however small, is of importance. If I put a piece of lead under the hammer and strike it, I cannot break it; or if I put a piece into a mortar I cannot powder it. Marble, then, is a substance entirely different from lead in these respects, inasmuch as the marble has the property of brittleness, which is not possessed by lead.

So much for the effect of a blow upon marble. Now let us try it in some other way; and first of all we will treat it with water. In these vessels are two large thermometers, which I hope will be visible from every part of the theatre; one of the vessels contains a substance which is somewhat of the nature of common salt; it is not common salt, but a substance called salt-cake (1)—a kind of salt that cakes together a good deal; in the other vessel I have put some coarsely-powdered common marble.

We are going to wet both these substances, and notice what happens. We will take a little water, and first of all wet this salt substance a little, and observe what takes place. And, now, having done this, we will wet the marble, and notice whether there is any difference between the results in the two cases. I think you will find, in the course of a very few minutes, that the liquid of this thermometer which is placed in the salt-cake, and which originally stood rather lower than the other thermometer, will rise rapidly, showing that a large amount of heat is evolved. Salt cake, then, is a substance which, when moistened with water, gives out a considerable amount of heat; whereas marble, when wetted, does *not*

give out heat. You see that the liquid in the thermometer connected with the salt cake is already gradually rising, and it will go on rising, I have no doubt, until it eventually reaches up to the very top of the stem. [At a subsequent stage of the lecture the professor pointed out that the thermometer had risen to a considerable height.] In this respect, then, we find a difference between the marble and the other substance.

And now let us try in some other ways the effects of water upon marble. You know that there are many substances which disappear when they are put into water; in other words, they dissolve in the water. Certain other substances do *not* disappear; you have a very good illustration of this in the case of sea salt and sea sand. You have observed, when you have been by the sea side, that the sea salt remains in the water, whereas the sand is deposited upon the shore. Now let us ascertain whether marble is a substance which, like sea salt, dissolves in water, or, like sea sand, remains undissolved; and as I have compared the marble with the lead and the salt cake, I will now compare it with certain substances which are soluble in water. I will first take a substance which possesses a colour; it is some of the

substance called aniline blue,—one of the colours made from coal tar. We will throw some of this blue colour into water, and now notice what happens. You see the beautiful coloured streaks which are gradually descending. You see, in fact, that in this case we are dealing with a soluble substance—a substance which dissolves very rapidly in water, and by its solution gives rise to these beautiful streaks of colour. Here, then, we have an illustration of a substance which is soluble in water, and, at the same time, possesses a very brilliant colour. We will now pass on to the consideration of another substance. It is one which is soluble in water, and is also very readily soluble in dilute spirit of wine ([2]). We take some of this substance, and put it into the funnel, and pour upon it some spirit of wine, and you observe that in this case, also, the substance dissolves readily in the liquid. You see at the present time a streak of red colouring matter gradually descending through the liquid. Here, then, you have another illustration of a substance which dissolves in water with tolerable facility.

Now, it is quite obvious that we must not compare marble with one of these beautiful coloured substances, but with some colour-

less substance, and for this purpose I will take some common salt. Into this funnel I will pour a quantity of common salt, so as in a great measure to fill the funnel : you see the funnel is now filled with salt. In the same way we will place in the other funnel some marble, and notice whether any difference is observable in the case of the funnel filled with marble and the funnel filled with salt. In this experiment we shall not see streaks of beautiful colour, but I think those who are near me will be able to observe that, in the case of the common salt, there is a stream of liquid—which is, in fact, a solution of salt—descending through the water beneath ; whereas nothing of the kind will be observable in the case of the marble. But whether it is so or not, there is one effect which I think will be noticed by all, namely, that in the course of ten minutes or so the whole of the salt which we have put into this funnel will disappear, whereas the marble will remain.

We come, then, to this conclusion—that marble is a substance which, so far as we have gone, does not dissolve perceptibly in water. Here we have some marble in a bottle of water, and it is quite clear that the whole of the marble does not dissolve ; but the question chemically is,

has *any* of the marble dissolved? Has the water any marble dissolved in it? I will show you the method which the chemist adopts to determine this. He takes a funnel with some filtering paper in it, and pours the liquid through the funnel; the object of this filtration being to remove any particles of marble which may be undissolved in the water. The question, then, that we have to consider is whether the filtered water has any marble in it, and to find out that point we take some of the water and boil it away. You know that when water is boiled it gradually gets less and less in quantity, and eventually boils entirely away. Now if this water is *nothing but water*, it will boil away and leave no residue; but if it is water containing marble, although the water evaporates, the marble will be left behind; and thus when we want to know whether the water has taken any marble into solution, we filter the liquid, and then boil it away, and observe whether or not there is a residue. So much, then, for the action of water upon marble.

The next substance whose action we will try on marble is a very common one, namely, vinegar. We will take some finely powdered marble and moisten it thoroughly with water,

and then we will act upon it with vinegar. We pour some vinegar upon the marble, and notice whether any effect takes place. We shall see in the course of a minute or two that a considerable action is going on; you will observe that the vinegar will become covered with froth. Now in this case the marble, which would not dissolve in water, is dissolving in the vinegar, and not only is it dissolving, but it is behaving very differently from the manner in which the common salt dissolved in this water [pointing to the solution of salt], and in which the magenta dissolved in this other vessel. You observe that the marble dissolves in the vinegar with a considerable amount of froth. Now what is the nature of that substance? Vinegar, you know, is a sour substance; to what does it owe this sourness? We find that it contains what is called an acid. Chemists are acquainted with a large number of sour substances called acids, to which they have given different names. This acid contained in vinegar is called the *acid* acid, or *acetic* acid; but the amount of acetic acid in vinegar is extremely small. Therefore, if, instead of taking vinegar, we take some of the substance which gives its sourness to vinegar—the acetic acid itself—we shall find,

that the action is much more decided. I will now employ acetic acid instead of vinegar, and you observe that the marble dissolves with considerable rapidity, and we get a far more marked effervescence than by means of the vinegar.

Now, as I have said, chemists are acquainted with a great number of different acids. There is this acetic acid, or the acid acid; then there is the acid which exists in sour grapes, and which is called tartaric acid; there is likewise an acid existing in sour lemons, called citric acid; an acid in apples, called malic acid; an acid in sorrel, called oxalic acid; then there is an acid obtained from sulphur, called sulphuric acid; another from nitre, called nitric acid; and, lastly, an acid from sea salt called muriatic acid. Now muriatic acid is the acid which we will try next.

You will find that muriatic acid is a much stronger acid than acetic acid, and that when we come to act upon marble with muriatic acid, we shall get a very much more rapid effervescence; indeed, the effervescence is so rapid, that I need not employ the marble in the fine state of division in which it was submitted to the action of the other acid. I will take some of this marble in the form of lumps, upon which the

vinegar would be almost without action, and upon which the acetic acid would have a very slight effect; but with the muriatic acid I can act upon the marble even in the form of these coarse broken pieces, and you see that in this case we get a very violent effervescence.

We have now ascertained these properties as belonging to marble;—that when it is subjected to a blow from a hammer it breaks readily; that when exposed to the action of water it does not dissolve; and that when acted upon by vinegar, acetic acid, or muriatic acid, it not only dissolves, but also gives rise to this phenomenon of frothing or effervescence.

Let us now examine the nature of this effervescence; and for this purpose we will try to perform the experiment in a somewhat different manner. I have here a jar containing some marble, and this marble is covered with water; at the top of the water is an inverted funnel, the object of which you will see presently. In this case, instead of using acetic acid, we will add some of the acid from sea salt, which we call muriatic acid; and you notice that we quickly get an abundant effervescence. We cover this with the funnel and fill up the vessel with water, and in a minute or two you will see the nature of this effervescence. It consists in

the formation of a large number of bubbles of air or gas under the water; and here you see these bubbles of air rushing up through the neck of the funnel into the water above.

Now I wonder whether we can collect any of these bubbles of gas, and find out what sort of air they consist of; we will try. Let us take this glass cylinder and fill it with water, and invert it over the bubbles. If I were to invert the cylinder just as it is, after being filled with water, you would find that the air would rush into the cylinder, and the water would simultaneously run out; but if I take the precaution to cover the mouth of the glass with a card, and then invert it so as to keep out the air, the water will remain in the cylinder perfectly well. The air cannot get in, and consequently the water cannot get out. If I put this card on the end of the glass cylinder, I prevent the air from gaining access, and consequently the water does not escape; when the air cannot get in, the water cannot get out.

I have here another arrangement of the same kind, and by it we will now endeavour to collect some of the gas which is coming up from the marble. I take this tube filled with water, and instead of closing it with a card, I simply close it with my thumb, and support the end of it under the

water over the bubbles of gas; and in this manner we shall no doubt be able to collect under the water some of these bubbles of air or gas which are rising from the marble, and which have been generated by the action of the muriatic acid upon the marble. We will now try to get some more of this gas from marble, by acting upon the marble with the acid in a bottle instead of in a cylinder. Here is some in a bottle, and in this way we get a considerable effervescence; we put into the neck of the bottle a cork, with a piece of bent tube attached to a piece of vulcanised tube, and we thus get a jar full of gas in a minute or two, for we are now performing the experiment on a somewhat large scale, while in the other case the scale was small. This effervescence consists in the formation of bubbles of air beneath the surface of the water, and these bubbles of air we collect. In a minute or two we shall have this jar full of the gas which is given off from the marble, and then, having obtained it, we shall be able to ascertain its nature. The vessel is now full of the gas from the marble, and so we will close it with a glass plate and put it aside for a minute or two, until we require it.

We have tried the effect of water and of acids upon our marble; now let us try the effect of heat. We will take some of

our finely powdered marble, and subject it to the action of a strong heat ; and at the same time that I pour some of the marble into this capsule I will also pour some more of the same marble into a glass which shall stand by the side of the capsule, so that when the experiment is complete we may know that we have two specimens of the same substance—one of them being the substance before the action of heat upon it, and the other being the same substance after it has been acted upon by heat. We will take this platinum dish or capsule containing the marble, and apply to it a strong heat. I will let it be uncovered at first, so that you may see how hot it becomes, and then, in order that the heat may be greater, we will cover it up with this platinum lid, which will cause it to become still hotter. [The dish containing the marble was then submitted to a blowpipe flame]. But I will also expose some marble to heat in another way; instead of putting it into a dish we will put it into this platinum tube, and having filled the tube with marble we will heat it very strongly, and notice what happens. Our tube is now full of marble ; we will, therefore, insert in one end of it a cork, having a glass tube passing through it, and we will heat the platinum tube very strongly by means of a blowpipe flame; but first we will attach

to the glass tube an apparatus for the purpose of ascertaining whether or not any kind of air or gas is given off under these circumstances. For this purpose we will take another glass cylinder and fill it with water, and invert it in a dish of water over the end of the tube from which the bubbles of gas issue, as in the former case. We are now making our platinum tube very hot by means of the blowpipe, and you will notice in a minute or two whether any gas is being evolved. We dip the mouth of the tube underneath the cylinder of water, and you will see that one of the effects of heat upon the marble contained in the tube is to drive off a kind of air or gas.

The point, then, to which we have now arrived is that, whether you act upon marble by an acid, or by heat, in either case a particular kind of air or gas is evolved.

This, then, is the question which arises. What is the nature of the gas or air which is given off in these cases? Does the marble evolve the same kind of air under the action of heat as under the action of the acids, or is it a different kind? The only way to answer this question, as well as a great number of others, is to experiment. We will try whether the kind of air given off by the action of heat is

the same that is given off by the action of the acid, or different; and for this purpose we will examine more particularly the nature of the air that is evolved by the marble through the effect of the acid upon it.

We will take a solution containing lead, very well known to medical men under the name of Goulard solution; it is a solution of basic sugar of lead ([3]). We will allow the gas given off by the marble to bubble up through our solution of basic sugar of lead, and see whether any action takes place; we see, in point of fact, that there is an effect, and that the solution is rapidly becoming milky. We will now take another portion of the gas given off from the marble under the action of the acid, and try in another way what its properties are; we will take a piece of lighted stick and immerse it in the gas, and it is, as you see, immediately extinguished. Thus, then, we find that the air which is given off from the marble by means of the acid has these two properties; it renders the sugar of lead solution white and turbid, and it extinguishes flame. We will now take a jar of the gas obtained from marble by the action of heat, and observe the effect of this gas upon the solution of sugar of lead. We cause some of the gas that has been produced from the marble

by heat to bubble up through a solution of sugar of lead, and you see that in this, as in the other case, the gas evolved from the marble has the property of rendering the basic sugar of lead turbid, like the gas evolved from the marble by the action of the acid. In this respect, therefore, the gas evolved from marble by these two different agencies appears to be the same in both instances. Now we will ascertain whether the gas which is evolved from marble by the action of heat has also the property of extinguishing flame. For this purpose we will get our cylinder full of the gas which has been expelled by the heat from the marble, and you see that directly I put in a lighted taper it is extinguished by the gas contained in the cylinder. We have therefore tried the gas produced by these two different methods, and we find that it behaves in the same way in both cases; and, in fact, I may tell you that, no matter how you subject to trial the gases evolved under these different kinds of action, you will find that they always behave in the same way, or, in other words, that the air given off from marble by the action of heat is identical with that evolved from marble by the action of acids.

Now let us see of what this residue consists; and for this purpose we will examine the

substance which we have been subjecting in this way to the action of heat. You will remember that in this vessel we had some of the original marble which we did not expose to heat; and now we will take some which has been exposed to heat, and see whether any difference is observable in the behaviour of the two sorts. Inasmuch as it is possible, and, in fact, very probable, that the action of the heat may not have been pushed sufficiently far, we will not take the whole of the marble which has been heated, but only a portion of it, and the remainder we will a little longer submit to the action of the heat. Before experimenting with this portion of the marble which has been strongly heated, we will wait a minute or two, that it may become a little cooler; at present it is so hot that I am not well able to bear my hand upon it. When it is cooler I will try the effect of water upon it, and we will see whether the marble which has been thus heated behaves in a different way from that which has not been heated. (It is now practically cold; it is not thoroughly cold, but I can bear my hand upon it.) You will now observe that directly I moisten with water the marble which has been heated, it gives out a great amount of heat and a great quantity of steam, and has now become so hot

that it is impossible for anyone to bear his hand upon it; whereas this marble which has not been submitted to the action of heat, is quite unaffected by the water with which I moisten it.

We will now go on a little further, and notice whether that marble which has been so strongly heated will effervesce under the action of an acid, and if it effervesces, whether it does so to the same extent as the original marble. In the case of the marble which has been heated, you see we get some effervescence, although not in the same degree; and I am in hopes that in a short time, when the remainder of the heated marble has been subjected a little longer to the heat, we shall get a product which will give us no effervescence.

Hitherto I have been talking about the observation of facts; here, you see, we have a fact which I did not want, for it was my intention that the marble which had been heated should not effervesce. Now, in science we must interpret the language of facts as they arise. This is an awkward fact; why did it happen? It was because we did not allow the action of the heat to continue sufficiently long. We shall have to go over the experiment again, but for the present you must take my word, that if the marble had been ignited sufficiently long it would not have

effervesced. I will give you another illustration of the great amount of heat that is produced by this residue when it is wetted. Here we have some large pieces of the residue left after ignition, and upon moistening them we get a very considerable amount of heat evolved. You will see the mass begin to steam in a minute or two. It already gets very hot (⁴); and if I place upon this mass of residue from the ignition of the marble a piece of phosphorus, you will see that in a minute or two the phosphorus will burst into flame. The phosphorus now takes fire from the heat that is in this way produced by wetting with water the residue left from the ignition of the marble. Thus you see that the substance which is left from the ignition is very different from the original marble. Now we will take a little more of this marble residue, which we will also wet with water, and we will notice whether any other remarkable effect takes place through the action of the water. We take our marble which has been burnt, and we will notice whether we get any solution; and for that purpose we will treat this liquid which we pour upon it exactly in the way we treated the liquid which was obtained by the action of water upon the marble before it was burnt—that is to say, we

will filter it—and then we will take the liquid obtained by the action of water upon the residue of the ignition of marble, and ascertain whether the water, which would take up nothing from the original marble, will take up anything from this residue of ignited marble. Here I have some of this solution filtering through the funnel; but here is some already made. First of all we will try its effect upon a piece of paper (5). This piece of paper, you see, is almost colourless: we dip it in the solution, and we find that it is dyed almost purple, showing that the water which has been obtained in this way has something in it. Here is another piece of paper; let us see whether the solution has any effect upon it. When I take out this piece of paper, you will observe that, whereas the first piece was of a bright red colour, this piece is very quickly stained green—not, I think, so decided a green as the other was a red, but still very apparent; you see, then, that the product obtained by the action of water upon the residue of ignited marble has certain properties. Here is another piece of paper, and you see that it is dyed brown by the action of the liquid. Here we have a piece of paper which is already red, and on our allowing it to come into contact with the liquid

it changes to a decided blue. In this way, then, we are able to ascertain that the liquid which is filtered from the residue of the ignition of marble has the property of affecting these bodies in these different ways. Now we will try its properties in another way. Here are some vessels containing certain metallic solutions. You will find that the water which has been allowed to digest on marble which has not been ignited, has no effect on the solutions, except that it makes them somewhat paler in colour, by diluting them; whereas I hope to show you that the water from the marble after it has been heated, has a very decided effect. [Portions of the liquid filtered from the calcined marble were added successively to the various metallic solutions ([a]).] Here we get a blue precipitate; here a black precipitate. To this we add some of the liquid in the same way, and we get a brown; into this, again, we put some of the liquid from the ignited marble, and we get a green; here, again, we have an orange colour. Lastly, we add some to this solution in the same way, and obtain a white precipitate. Hence you see that, while the water filtered from the unburnt marble has no effect upon these solutions, the water which has acted upon the marble after ignition produces a very decided effect.

Now, what is the nature of this substance which is left behind after the ignition of the marble? It is known as "quick-lime." When marble is heated in this way we get a substance which differs very much from the original; it is no longer marble; it has not the property of effervescence with acids, but it has the property of forming a solution with water and giving out heat when moistened. Marble is a substance which does not give out heat on being wetted, and does not dissolve; marble effervesces with acids, but the quick-lime does not. So much, then, for the residue.

Next, what is the nature of the gas which is produced when the marble is heated and the residue of quick-lime is obtained? Here is an arrangement which is rather more convenient for obtaining the gas for lecture purposes than the one employed before. It is exactly of the same character, only in this we have the marble in a separate vessel, where the acid can act upon it at leisure. Here we take some of our lime-water, and we cause some of this gas to bubble through it, and we note what effect takes place. When we allow the acid to come into contact with the marble we get an abundance of the air or gas given off, and we found that the same air or

gas was given off by the marble whether through the action of acid or of heat. Some of this gas is allowed to act upon this lime-water, and we find that we get a substance identical with the original marble with which we started. We will try this product, and I have no doubt those who are near me will see that a gas is given off when I add muriatic acid to it. [The precipitate effervesced on being treated with acid].

From what we have seen, then, we conclude that lime differs from the original marble in the absence of this particular kind of gas or air which the marble gives off when it is heated; and you noticed just now that when we caused this gas to re-combine with the lime we obtained a substance possessing the properties of the original marble; and when we took this precipitate from the lime-water and acted upon it with muriatic acid, you saw that we obtained the gas once more driven off, and the precipitated marble dissolved. The precipitate which was produced we say is *chemically* the same thing as marble.

Let me next call your attention to some other kinds of marble. Here is a piece of coral; here a piece of stalactite; this is a piece of calcareous spar; this of limestone; and this a piece of shell. If we take some of these shells, and cover them with water, and act upon them

with muriatic acid, we shall obtain, as before, a considerable amount of effervescence, due to the solution of the shells in the acid and the evolution of a gas. Directly we pour some of this acid upon them, the shells undergo solution, and immediately effervesce; pearls also act thus. For instance, if we take some pearls, and act upon them with hydrochloric acid, we shall find that they dissolve and give off gas. I have spoken of this gas as being the gas of marble; I may also call it the gas of pearls. We moisten these pearls with water, and act upon them by muriatic acid, and we get a rapid effervescence, and in this way we might collect the gas given off by pearls. You will remember, I dare say, the story of Cleopatra melting her pearl ear-rings in vinegar; all I can say is that either her vinegar must have been extremely strong, or she must have taken a very considerable time about it, for pearls dissolve very slowly in vinegar, though they dissolve more readily in this strong muriatic acid. We will facilitate the action of the muriatic acid upon the pearls by the application of a gentle heat, for in this case, although the substance is chemically identical with marble, it is in so compact a state that even the muriatic acid acts upon it very slowly, and the vinegar which Cleopatra is

supposed to have employed scarcely acts upon it at all. Now we are collecting our gas from the pearls, and the action will go on in this way until we get our cylinder full of the gas.

I next want to call your attention, for the few minutes that remain, to some of the properties of this gas; first of all to the combustion of metals in it; for although the gas given off from marble is not capable of supporting the combustion of ordinary combustibles, it can nevertheless support the combustion of some bodies. In the first place, in order to prove to you that metals will burn, I will show you the combustion of certain metals in the air, and then we will take one of them and burn it in the gas given off from marble.

I will here ignite some zinc, and then blow a current of air upon it, and you will find that in this way the zinc burns very readily. Zinc, then, is a metal capable of burning very readily in air. Now let us try the combustion of the metal magnesium in the air; you have seen that metal burn in the air on several occasions. Here is a piece of magnesium burning in the air very readily and with considerable brilliancy. Now I want to show you the combustion of a metal, both in air and in the gas given off from marble, and that

metal is neither of those that we have yet considered; it is the one which I am now about to ignite—metallic sodium. It is now beginning to burn with very great brilliancy, and whilst it is burning let me draw your attention to the remarkable appearance which that coloured diagram presents when illuminated with the light given off by burning sodium ([7]). What were seen to be brilliant colours when the magnesium was burning, now look perfectly black under the influence of the sodium light.

The only other experiment to which I wish to call your attention this afternoon, is the combustion of this metal—sodium—not in ordinary air, but in the particular kind of air that is evolved from marble. We take our apparatus which is giving off the gas from the marble, and we cause this gas to flow through pumice-stone moistened with oil of vitriol, for the sake of rendering it dry, and then we receive it into this flask. We next heat our sodium as we did just now, except that instead of heating it in the open air we heat it in the flask in a current of this gas, and I want to show you then what the effect will be. [A piece of sodium was deposited in a flask which had been filled with the dried gas; the sodium was then ignited by the application of a blow-pipe flame to the

exterior of the flask]. The sodium has now, you see, taken fire, and is burning in the gas contained in the flask; and now the only other point that I have to call your attention to is the result of this burning. When we come to examine the contents of the flask, what do we find as the product of the combustion of the sodium in the gas evolved from marble? As soon as the mass at the bottom of the flask ceases to be red hot, I will ask you to observe its appearance. You now see that we have here a solid mass of that black substance—charcoal—to which I directed your attention at the beginning of the lecture. Well, now, where did this piece of charcoal come from? It could not have come out of the sodium, and for this reason,—that if you take this metal and burn it in the air, or in any other gas or under any of the conditions under which sodium is capable of burning, in no case do you get this charcoal except when it is burnt in this gas which is given off by marble. The point, then, to which we have arrived at the conclusion of this lecture is—that marble is capable of evolving a certain kind of air or gas, and that this air or gas contains charcoal as its essential constituent.

LECTURE II.

CARBONIC GAS—AIR—OXIDES.

I FEAR that in my last lecture I did not address myself sufficiently to those of you for whom this course of lectures is especially intended; this fault I must try to mend upon the present occasion. To-day, then, we will have the lecture entirely to ourselves, and disregard those full-grown people who sit upon the hinder benches. Now, as I am only going to talk to *you*, I shall not hesitate to venture upon a little recapitulation; and I wish to call your attention to some of the ground that we went over two days ago. You remember we began with marble. I told you that marble is characterised by certain very well-defined properties. It is not one of those substances which become hot when moistened with water; it will not dissolve in water, but it *does* dissolve in acids; and when it dissolves, the act of solution is

attended by that particular kind of action which is called effervescence or frothing. Now you will remember that this effervescence really consists in the formation or liberation of a particular kind of air or gas under the surface of the water. Here is the solution of the marble in acid going on. You see it is accompanied with an effervescence, and this effervescence consists in the formation of bubbles of air or gas which we are collecting in this tube. Then we spoke of the action of heat upon marble; and you will remember, also, when the marble is heated very strongly—in this tube, for instance—it gives out a quantity of air, and we find that the air given out from marble, when subjected to a strong heat, is identical with the air evolved from marble by the action of acids.

I next proceed to examine the residue; of what does it consist? We find that it consists of quick-lime, and that this quick-lime differs from marble in several particulars.

First, unlike marble, it becomes extremely hot directly we moisten it with water; unlike marble, it dissolves in water, and forms the perfectly clear solution called lime-water. Lime dissolves in water, marble does not; and, unlike marble, the lime, when acted upon by acids, does not give off any kind of air or gas.

We find, then, that marble, when strongly heated, is resolved into a particular kind of air or gas which we are here collecting, and into a residue of quick-lime capable of being dissolved in water.

Now what will happen if we take some of the gas evolved from the marble by the action of heat, or some of the gas obtained from the action of acids, and pass it through lime-water? Here you see we are separating our marble into quick-lime which remains behind, and this particular kind of air or gas which is being collected. Here, again, is the same kind of air or gas—generated in this case by the action of an acid, instead of by the action of heat—and we pass it through our lime-water, and re-produce a substance which is no longer soluble in water. This substance is, in fact, the same chemical compound as the marble with which we began. In one apparatus we decompose marble into gas and quick-lime, and in the other we re-form the marble by combining with the quick-lime the gas evolved from marble by the action of acids. But we may also form marble by using the gas evolved under the action of heat. If, instead of collecting the gas produced from the marble by the action of heat, we allow it to bubble up through this lime-water, you see that

in this case, also, we reproduce, in a different form, the marble which we are decomposing by heat in the tube.

Now I call this precipitated substance "marble," but that is not strictly correct. This substance has the same composition as marble, but it is not marble itself, because we apply the term "marble," not to a substance which merely has the same chemical composition as marble, but to one having certain physical properties. You will remember that, on the last occasion we spoke about this piece of marble, and I then called your attention to the fact that it was a brittle substance; but this precipitate that we now have is no longer brittle; indeed, though it is the same thing *chemically* as marble, it is not the same thing *mechanically*. It is chemically the same as marble, just as shells are the same as marble. For shells, when they are acted upon by acid, dissolve in it like marble, and give rise also to the phenomenon of effervescence. Here we have a piece of coral dissolving in the acid with effervescence, and giving off exactly the same kind of gas as marble; so that, although we have hitherto spoken of this gas as being the gas from marble, we might also call it the gas from shell, the gas from coral, the gas

from limestone, or even the gas from pearls.

Now for a word or two about lime. Lime differs from marble in that it does not effervesce when acids are added to it, and the reason of this you will very readily see. The gas which is given off by heating marble so as to leave the quick-lime is identical with that given off by the action of acids upon marble; and if we first drive off all the gas by heat, of course there is no more left in the marble to be driven off when we act upon it by acids. The marble so heated no longer effervesces with acids, because the whole of the air which it contained has been driven off by heat. In this way we learn that marble is a compound of quick-lime with the air or gas which is evolved.

I told you that this precipitate was chemically the same as marble, and as such it ought to be dissolved by acids with effervescence, like the original marble. [Some muriatic acid was added to the water containing the precipitate suspended in it.] In this case you see we get a considerable amount of effervescence; there is a distinct frothing on the top of the water from the effervescence which is now taking place. Well, all these substances—shell, coral, pearl, this precipitated chalk, and limestone—

are converted into quick-lime by heating ; and all effervesce with acids, giving off this particular kind of gas.

Now, what is the nature of this air which is evolved ? In the first place, we have seen that it has the property of rendering lime-water milky; in the next place we shall find that it has the property of extinguishing the flame of ordinary combustibles. To begin with, we will take this particular portion of gas which we first produced, and lower into it a burning rod of wood. You see the light is immediately extinguished; and not only will the flame of the burning wood be extinguished, but also the flame of burning gas. We introduce a jet of ordinary gas, and it is at once put out; we ascertain, then, that wood and gas are two substances which will not burn in the air evolved from marble. Let us try another substance. We will take this small piece of candle, and observe whether the same thing will occur. Our piece of candle burns perfectly well in ordinary air; let us see whether it will burn in the air from marble. We introduce it; the flame at once goes out. From this we learn that ordinary substances, at any rate, will not burn in the gas from marble.

But chemists, as I told you on the last occasion, are acquainted not only with ordinary,

but also with extraordinary combustibles. Zinc, magnesium, sodium, and iron, although not usually regarded as combustibles, nevertheless are such in the eyes of the chemist; they have the property of burning in the air. Now this particular substance—sodium—not only possesses the property of burning like ordinary combustibles in air, but it also burns in the gas from marble; and at the end of the last lecture, when heated in the gas, this particular sodium not only burned with great brilliancy, but it produced a very extraordinary result. Here is the flask in which we performed the experiment, and we found in it a large piece of charcoal. Where did that charcoal come from? It did not come from the sodium, as we know, for this reason: you may treat sodium in all sorts of ways—burn it in the air, or in a variety of gases; but do what you will with it you cannot get any charcoal out by it, unless you employ some substance which, like the gas obtained from marble, contains charcoal; and we may not only get charcoal from the gas by means of sodium, but by a variety of other substances, and therefore we are led to the conclusion that the charcoal came from the gas of the marble, and that this gas or air evolved from marble contains charcoal as an essential constituent.

I have hitherto called this gas *air or gas from marble;* I ought to tell you that it was originally called *fixed air*, because it is capable of being fixed or absorbed by lime. It is now called *carbonic gas*, because it is the air or gas from charcoal or carbon. Marble, then, is a compound of quick-lime with carbonic gas, and is called chemically *carbonate of lime*.

The next thing to consider is whether, since we can get charcoal out of carbonic gas, we cannot produce carbonic gas from charcoal as well as from marble. First, let me explain to you the method of ascertaining the presence of this gas; the test used for this purpose is lime-water. The carbonic gas forms with the lime-water an insoluble compound—chalk—and accordingly, when we find that a gas passed through lime-water converts it into this substance, we know that we are dealing with carbonic gas—the gas containing charcoal. Now let us see whether we can produce any of our carbonic gas from charcoal. Here is a tube passing into some lime-water; we draw air from this burning charcoal through the tube into the lime-water, which, though at first perfectly clear, is now converted into a mixture of chalk and water. We convert the lime into chalk, a proof that we are dealing with that particular

kind of gas which has the property of rendering lime-water turbid; and thus we know that by burning this charcoal we are converting it into carbonic gas.

Now, carbonic gas is produced not only by the burning of charcoal, but also by burning ordinary combustibles. Here are some bottles, which in the usual acceptation of the term are empty; that is to say, they are full of air and nothing else, and would be therefore termed empty. We will first hold one of these bottles over an ordinary gas flame, and then pour into it a little lime-water; we shake it up for a minute or two, and you see our lime-water is converted into chalk, and we find that ordinary gas also has the property of forming this carbonic gas or fixed air. We will now try another combustible —a piece of wood—which we will take in the same way, and allow it to burn inside the bottle, and notice whether, under these circumstances, we obtain this carbonic gas. We will add to it some lime-water, and we shall find in this case, as in the other, that our lime-water becomes milky from the formation of chalk, showing that not only charcoal and coal gas, but wood also, when burnt, has the property of producing this particular kind of gas which we obtain from marble. We will now take another

combustible—a taper—and burn it in the same way in the other empty bottle, and notice whether any carbonic gas or fixed air is produced; we observe that here, also, our clear lime-water is converted into a chalky liquid. We see, then, that carbonic gas is thrown into the atmosphere by all ordinary burning bodies—by the burning charcoal, the coal gas, the wood, and by the taper.

Now, are there any other means by which carbonic gas is discharged into the atmosphere? One other is decay. You all know that in autumn the leaves fall off the trees, and sometimes accumulate till they are up to your ankles, or even higher. I have not any decaying leaves to experiment with, but I have some rotten wood; and I want to show you that from this, and from the rotting of leaves, sawdust, and bodies generally, we get carbonic gas. Here is a tube in the shape of the letter U, containing some lime-water, and we will suck the air from this tube through the lime-water, and you will see that the rotting wood has the property of giving off this carbonic gas and rendering the lime-water turbid. Decaying leaves and decaying sawdust would do the same.

Another way in which this gas is also discharged into the atmosphere is by breathing.

Here we will vary the experiment a little by putting the lime-water into the bottle first. I will shake it up to show you that there is nothing formed at present ; I will not shake it violently, or it would form a froth which you might mistake for the whitening of the liquid by the formation of chalk. I now breathe into the bottle, and shake up the contents as I did before ; and you will observe that the soluble lime is at once converted into chalk.

You see, then, that this gas from chalk or marble is constantly poured into the atmosphere from endless sources—from all burning bodies, from all decaying bodies, and from all breathing animals. Now is there any other source ? In various parts of the earth, more particularly in volcanic districts, we find that quantities of this gas issue from the earth with enormous force. Indeed, so great is the quantity, that it is probable that the amount of this fixed air evolved into the atmosphere from fissures in the earth, and from caves, and volcanoes, and similar sources, far exceeds that which is discharged into the atmosphere by all the fires, all the decay, and all the breathing animals on the surface of the earth. Now I cannot bring you any of this natural gas bottled up—at least, not very conveniently ; but it may be obtained

in other ways. That which issues from the surface of the earth sometimes comes up in the form of gas; but sometimes we find water saturated with it—and this is the nature of the natural effervescing waters, such as the Seltzer water (8), which is imported into this country in bottles, and of the Brighton, or artificial Seltzer which is made to imitate the natural water. In these waters a large quantity of the gas is condensed, and it is given off from them just as it is evolved from charcoal by burning it. We will put a screw tap into a bottle of Seltzer water, and see whether any carbonic gas is evolved. We turn the tap, and collect some of the gas which is given off, and we find that it is identical with the carbonic gas we have been considering. This illustrates one of the many natural sources of this gas.

You will perceive, then, that in consequence of the constant occurrence in nature of the actions which I have mentioned, the air by which we are surrounded must contain carbonic gas, and, as a natural consequence, charcoal. The invisible air which surrounds us really contains charcoal in the form of an invisible gas, and you would, perhaps, think that from the existence of so many natural sources of the gas, the proportion of it in the air

is very large; but in reality it is extremely small—amounting to only half a part in a a thousand; in fact, it is rather less than half a part, but I state it broadly that you may remember it (9). Now, I can give you some illustration of the quantity by means of an experiment. I have here a tube which contains this carbonic gas, and into the tube I put, not lime-water, but milk of lime—a mixture of lime and water, containing more lime than the water can dissolve. We now shake up the tube of gas and then open it under water; we pour in some more of this milk of lime, and we shall be able by repeating this to dissolve the whole of this kind of air, which, you remember, is called fixed air, because lime has the property of fixing it. I close the end of the tube with my thumb, and shake up the lime with the air of the tube, and again open it under water. You see, the water immediately rises to a considerable height in the tube, and if we continue to operate in this way it will at last rise to the extreme top; this shows that the lime has the property of completely absorbing this gas. Now if we take this other tube, which only contains common air, and treat it in the same way, the quantity of carbonic gas in the ordinary air is so very small that you will not notice any absorption whatever. I close

the tube with my thumb, and shake it up as I did the other, and then insert it under the water and open it, and you will notice that there is practically no absorption, or rather the amount of absorption is so small that you cannot see it. It amounts to only half a part in a thousand.

Nevertheless, I can show you the presence of this gas in the air if I adopt certain means. I will take some lime-water, and introduce it into this tube in front of you. Here is a vessel, termed an aspirator, filled with coloured water; and if I turn the stop-cock, and allow the water to run out, you will observe that, as it does so, the air must be sucked through the lime-water to fill its place; and I daresay that by the end of the lecture we shall have drawn through the lime-water a sufficient volume of air to affect it and render it turbid.

The action is here going on in another way. In this dish I have placed some lime-water, which was originally perfectly clear and brilliant. If you look at it after the lecture you will see that it will be covered with a scum of chalk, due to the carbonic gas in the air of the room. In this way we find that carbonic gas, and consequently charcoal, is a constant constituent of atmospheric air.

I want now to consider how it is that this car-

bonic gas gets into the air—by what process charcoal is converted into carbonic gas, and how it is that the air contains it; and for this purpose it is necessary that we should again turn our attention from charcoal, and for a few minutes consider the nature of air. I must here bring before you some historical facts in connection with it. What sort of a substance is air?

The first point I want to impress upon your minds is that air is a real material substance. At the commencement of my first lecture I told you that you had come to the Royal Institution to learn about *things*—things that could be touched and weighed. Now I am talking to you about air. Is air a *thing*—something that can be touched and weighed? Let us begin gradually; if we take a block of wood and press it between our hands, we find that it is sensible to the touch. This capability of being felt has received various names. Sometimes it is called *impenetrability*, because one body cannot occupy or penetrate the space that is being occupied by another; sometimes it is called *extension* because the body extends, between my hands for instance, and keeps them apart; but it is more commonly called *resistance*, because the substance resists, just as this

wood resists, my hands. Whether you call this property inpenetrability, extension, or resistance, the word means the same thing. It means that the body is capable of being felt. A solid body, we know, can be felt, but when I press sand between my hands, it does not keep them apart like the block of wood. Hence you would perhaps say at first sight that the sand does not possess this property of impenetrability, or extension, or resistance; but if we put the sand into a bag so that it cannot make way for my fingers, it then keeps them apart, and resists their pressure just as the block of wood did, and so we must say that it has impenetrability. A tight bag of sand may be regarded almost as a hard solid substance; it is capable of striking a very heavy blow, and, indeed, was formerly used for that purpose. When we pass from such a substance as sand to a liquid substance like water, we find that it keeps the hands apart still less forcibly than the sand, and you may say that it is perfectly penetrable. Well, it *is* penetrable in one sense, but not in another. If I put water into a bladder, the water not then being able to make way for my fingers, will keep them apart, and this is what we call the capability of being felt—the property of impenetrability or extension. Again, we cannot, under ordinary circumstances,

feel the air, but if it is placed in a bag, like sand or water, we can feel it perfectly well. Here I have a bladder of air, and I can feel that there is something in it which my fingers cannot penetrate—which resists their pressure—which extends between them; and therefore we say that the air is possessed of this capability of being felt, and this constitutes it a *thing*. But is it also capable of being weighed? Can we weigh air? I think we can. Here is a flask from which the air has been removed by a means to which I do not intend at present to direct your attention. We place this flask on a balance, and it is now more than counterpoised by a weight on the opposite side, which is heavier than the flask. I will let the air rush into the flask, and you will see that under these circumstances the flask will become heavier than the weight: at present the counterpoise is the heavier of the two. Now listen!—[opening the stopcock to admit the air.] You hear the air going in, and you see that the flask becomes heavier than the weight on the other side of the balance.

Not only is air actually possessed of weight, but it is really very heavy. A cubic foot of air weighs something between an ounce and an ounce and a quarter ([10]). You might think that we ought to be able to feel its weight, and here I will

devote a few minutes to explaining to you the recognition of atmospheric air as a material substance. Thoughtful people in all ages have taken note of the air, but there must have been a lapse of at least 2,000 years between the first scientific notice of the air and the discovery of the fact that it was a thing or substance. It was not until the year 1643 that atmospheric air was recognised to be a substance possessed of weight and capable of being felt; so that, although the air is a weighty substance, its weight is not very easily appreciated. You are not yourselves sensible of its being weighty, and for 2,000 years after mankind had begun to think of it, and perhaps for as many years before, they were quite unconscious that it was a substance possessed of weight. They said that if it was heavy its weight ought to be perceptible. Now the reverse is the truth; if it is weighty you ought *not* to feel it. It would take me too long to explain this to you, so I will give you an illustration instead, and I want you all to see it. Here is a large tube closed with a bladder; at present it is nearly full of coloured water, and it is quite obvious that the bladder has to support the weight of the water, and from this cause you see it becomes extremely taut, and shows unmistakably that the water is

pressing upon it. If I lower the tube into this jar containing colourless water, so that the water is as high outside as it is inside, you will see that the bladder becomes insensible to the weight of the water. There is water as before, but still it is so exactly balanced on each side that the bladder is no longer conscious of it. Now again, [lifting the tube out] the bladder is extremely taut: very likely a little more would burst it; but directly I lower it into the vessel so as to have the water level on the inside and outside of the tube, the bladder becomes perfectly flaccid and insensible to the weight of the water, just as we are unconscious of the weight of the air by which we are surrounded. Take another illustration. In each of the pans of this balance is a pound weight, and they are now perfectly equipoised. Under ordinary circumstances a feather would be quite incapable of raising a pound weight, but in this instance you will see that it will be able do so. If I take this feather in my hand and gently raise it under one of the pans containing a pound weight, it elevates it above the other; the reason of this is, that the weight on the one side is so exactly balanced by that on the other, that the feather is not sensible of the weight it is moving. In the same way we are un-

conscious of the weight of the air in which we live, because that weight is not really supported by ourselves, but by the gravity of the surrounding air. So much, then, for the question of the weight of air.

The discovery of the gravity of the air was made in 1643; from that date to the year 1756 mankind were of opinion that there was only one kind of air, although many of them knew that air could vary in some respects. They were aware, for instance, that the air of the town differed from that of the sea—that some air had different properties from other air; but they never recognised these different kinds as distinct substances. They rather looked upon the difference as being similar to that existing between different sorts of water. You know there is rain water, river water, sea water, and spring water; but all these consist essentially of the same substance—water—together with certain impurities. Well, from the year 1643 to 1756 mankind thought there was but one kind of air, and that the differences were due to impurities which gave the various airs a different character, just as sea water differs from common water because there is a little sea-salt dissolved in it, and so on. In reality, however, there are essentially different kinds of air.

First of all, we find there are airs of different colours; here is some of a decided green; in this other bottle we have some of a brown colour ([11])—so that we are acquainted not only with colourless air, but with airs of different colours, just as we may have liquids of various colours; and when we recognise no difference between airs by the colour, we may distinguish them by other methods. For instance, if I take a taper and introduce it into what we call an empty bottle—that is, a bottle containing ordinary air—the taper continues to burn perfectly well; but if I take it out of the bottle containing ordinary air, and insert it into this other bottle, we find that the taper is at once extinguished by our old friend, fixed air, or carbonic gas; and this was the first air observed to differ from ordinary air. It was discovered in 1756, and it differs from ordinary air in that it contains carbon.

We will now take another kind of air, which is colourless, and looks like ordinary air; we will apply a light to it and try what will be the effect —whether our taper will continue to burn. [On the experiment being tried, the light was immediately extinguished.]

This, then, is a fourth kind called *azotic* air. Those of you who are Greek scholars will know that azotic air means lifeless

air, and it was so called because it will not support life; it has also been called *phlogistic* air; it is now termed *nitrogen* gas, because it is capable of producing, or being produced from, nitre.

Here we have some air, which, when a light is applied to it, burns with a flame. This air was originally termed *inflammable* air; it is now called *hydrogen* gas, because it enters into the composition of water.

You saw that when I introduced the taper into the azotic air, or nitrogen gas, the light at once went out. In this respect, then, azotic air behaves exactly like carbonic gas; but it differs from carbonic gas in this particular—it is not capable of being fixed by means of lime-water. We will shake up some of this gas with lime-water, which, you observe, remains perfectly clear; whereas, if we had taken the bottle containing carbonic gas, the lime-water would have become milky, in consequence of the formation of chalk. This azotic air therefore corresponds with the fixed air in not allowing bodies to burn in it, but it differs from the fixed air in not rendering the lime-water turbid.

We now come to another kind of air, which was discovered in 1774, and was originally termed

vital air; we now call it *oxygen* gas. On introducing the lighted taper into this oxygen, we shall see whether it burns as in ordinary air, whether the gas takes fire, or what happens to the taper. We introduce it, and you see with what increased brilliancy the taper burns. Here, then, we are dealing with a fourth kind of air.

I will finally call your attention to a seventh kind, called *marsh* gas; this is an essential constituent of ordinary coal gas. You are all familiar with the appearance coal gas presents when it is being used in the ordinary way for lighting. You observe, when we set fire to this marsh gas, it at once burns in a similar way. It was originally called heavy inflammable air, because it is much heavier than ordinary inflammable air, or hydrogen. Thus, you see, chemists are acquainted with many varieties of air.

We will now return to this fixed air, or carbonic gas, or gas from charcoal, and the way in which it gets into the atmosphere. And this leads me to make some remarks on the miscibility of different kinds of air one with another. I will illustrate this by reference to certain liquids, and first let me call your attention to this cylinder, at the bottom of which I have poured some

of the heavy liquid, mercury. Upon the mercury is the colourless liquid, chloroform, which is also heavy; and then upon that, some water which I have coloured in order to make it more evident. Thus we have three different liquids in the cylinder, standing in layers one upon the other, and not capable of mixing. If I put a stick into them, and stir them up, they soon settle again into distinct layers. I can even pour upon the water another liquid, ether; and in this way we shall have four liquids together in the vessel—mercury at the bottom, chloroform next, then the coloured water, and the colourless ether at the top—none of which are capable of mixing ([12]).

There are, however, certain other liquids which will mix with each other, and I will now draw your attention to some of them. Here is another cylinder, with some coloured liquid at the bottom and a colourless liquid at the top; the first is coloured water, and the other is spirit of wine. If I stir these liquids, they mix, and will not again separate. Here, again, is a cylinder which looks at first sight as if it contained only one liquid, but, in point of fact, it contains two—water at the bottom, and spirit of wine at the top; and I daresay I can render this evident to you. If I introduce

a piece of wax into the cylinder, and allow it to drop gently into the liquid, you see it sinks only half way; the wax drops through the spirit of wine, for it is heavier; but being lighter than the water, it floats on the top. In such cases, although the liquids are capable of mixing, when one is lighter than the other you may, with care, put the lighter liquid on the top of the heavier one. Now, if I shake these together, I get a mixture of spirit and water containing so much water that the wax at once floats at the top. In point of fact, then, these liquids do not differ so much from one another with regard to their miscibility as those to which I just now directed your attention.

Thus, with regard to liquids, we find that some will mix and others will not, but with regard to gases, we find that all of them will mix; we can put one kind of gas at the top of another, and keep it so for a short space, but after a time the two will mix completely. For instance, here is a brown-coloured gas. Now on the top of this I can put a cylinder of air, and we shall then have a colourless gas floating on the top of a coloured one, just as we had a coloured liquid floating on the top of a colourless one; but you will observe that

the brown gas will gradually mix with the colourless gas, even without much agitation.

We will now take another illustration, and one in which we shall be able to make a comparison similar to the floating of the piece of wax on the surface of the lower liquid. Here is a cylinder apparently empty, but in reality containing at the bottom some fixed air, whilst the upper portion is filled with ordinary air. Thus we have two colourless gases in the cylinder just as there were two colourless liquids in the vessel we had before us just now. I shall be able to show you the point to which the lower gas rises. If we introduce into this cylinder a jet of burning gas, the flame keeps alight while in the air, but when we allow it to go a little lower it comes into the fixed air, and is immediately extinguished. You see, then, that this jet of flame finds out the margin of the heavy and the light gas just as the wax found out the limit of the two liquids; directly it is lowered into the carbonic gas it ceases to burn. You see, therefore, that in the same cylinder we may have two different kinds of air floating one on the top of the other, just as we may have two liquids one above the other; but eventually you will find in the case of the gases that,

whether they are in a state of agitation or at rest, they will mix perfectly with each other.

Now comes the question,—Is the ordinary atmospheric air with which we have to deal a single gas or a mixture of different gases? I might call your attention to a great many experiments illustrative of the fact, that ordinary atmospheric air is really a mixture; and here is one. You know that many metals have the property of rusting. Some of them rust very quickly, like iron: others rust very slowly, like mercury, copper, or silver. Now, if you take such a metal as iron, which rusts tolerably quickly, and put it into a confined space of air, it gradually rusts, and as it does so the volume of air grows less and less until, in fact, the five volumes of air are reduced to four; now, this has taken place in the present instance. Here I have a cylinder which was full of air; some iron wire was put into it, and it has at last sucked up one-fifth of the air. Here, again, is a piece of phosphorus on the end of a stick; it is rusting just in the same way; and it will continue to do so until the liquid in the cylinder rises up one-fifth, and then the rusting will entirely stop. We find, then, that one-fifth of the bulk of the air is capable of being absorbed

by rusting iron and rusting phosphorus, and also by burning phosphorus. We will take some phosphorus and burn it under a cylinder inverted over water. We dry a small piece of phosphorus on paper, place it on a piece of cork, and burn it under the cylinder; and, as it burns, you will find that the water will gradually rise in the cylinder until it reaches one-fifth of the way up. [The experiment was performed with the result described.] Now, instead of burning a piece of phosphorus, I will in the same way burn a piece of candle also floating upon cork, and you will see, as before, that as the candle burns, the water rises in the glass vessel.

I must defer further consideration of the miscibility of different kinds of gas till my next lecture; but before I conclude I wish to show you two more illustrative experiments.

First, I told you that air is a material substance. I will now give you an illustration of it; this flask of coloured water is inverted over what appears to be an empty bottle, and the neck of the upper flask communicates with the neck of the lower vessel. Now why does not the water run out into this lower flask? Because that flask is *already full.* It is quite full of air, which cannot get out, and there-

fore the water from the upper bottle cannot get in ; but if I, for a moment, allow the air to escape from the lower flask, the water will run in from the upper vessel. If I close the receiver, you see that the water almost immediately ceases to run, because the air contained in the receiver cannot escape to make room for it.

The other experiment is one intended to illustrate the way in which air tends to magnify the appearance of some substances. Here we have a large glass jar which appears to be full of cotton wool. In reality, cotton wool occupies a very small portion of the jar, which is filled chiefly with air. I daresay you will be surprised to find that the whole of the wool may easily be put into this cylinder which seems to be already almost full of spirit. [The smaller cylinder was of about one-eighth the capacity of the large cylinder containing the dry wool, and was nearly full of spirit of wine.] I have coloured the spirit blue to make it visible to you all. [The lecturer then began to transfer the wool from the large jar into the small vessel containing the spirit; the wool so transferred was compressed at the bottom of the liquid by means of a glass rod. After continuing the operation for a short time the lecturer pro-

ceeded]— We have put a large portion of the wool into the cylinder, but it is not full; apparently it is no fuller than it was before, and if I put the wool in carefully I should be able to go on until the whole of it was transferred.

LECTURE III.

CARBONIC GAS—AIR—OXIDES.

YOU will remember that when charcoal or carbon burns in air it is changed into carbonic gas; we have now to consider what is the nature of this change—what it is that happens to the charcoal, and what to the air in which the charcoal burns.

In order to find out what occurs to the air we must first know a little more about it, and particularly whether ordinary air, in which the combustion of charcoal and other combustibles takes place, consists of one kind of air only, or is a mixture of two or more different kinds. You will remember that all kinds of air are miscible with each other; in this respect they differ from liquids, and accordingly we have this morning to begin our consideration of the question whether air consists of one kind only, or of two or more different kinds.

But first I want to direct your attention for a moment or two to an experiment which I will now commence, as it takes some little time, and in half an hour we shall, perhaps, see the result.

Here I have an ordinary transparent glass tube, which is filled with pieces of broken white porcelain, and through this tube I am going to pass a current of ordinary coal gas. The coal gas is now passing through the tube; I will just let it blow out the air with which the tube was first filled, and then I will apply a light to it. Now you observe that the tube is filled, and that the gas burns in the ordinary way in which coal gas burns; it is passing through the porcelain, but does not at present produce an effect. I am going to repeat the experiment with this difference—that the tube instead of being cold will be made red hot, and after the porcelain has been heated some time in the furnace, we shall see whether it has undergone any change. [Near the close of the discourse, the lecturer again drew attention to this experiment, and pointed out that, under the influence of the strong heat which had been applied to the tube, the coal gas had deposited a portion of its carbon; the separation of the carbon being evidenced by the blackening of the porcelain.]

We will now proceed to the consideration of the nature of ordinary atmospheric air.

When a body—iron wire, for instance—rusts in the air, this is the sort of thing that occurs. If you take five measures of air, and put the iron wire into them, they grow gradually less and less in bulk; a portion of the air becomes absorbed by the iron wire until a certain point is reached, at which exactly one-fifth of the entire quantity of air has been absorbed, and when this has taken place, the rusting action ceases. The absorption goes on no longer, and the remaining four measures of air are of a very different character from the original five; metals will no longer rust in them, bodies will no longer burn in them, and animals will no longer breathe in them. Apparently, therefore, the whole of the gas which enables metals to rust, combustibles to burn, and animals to breathe, exists in the one-fifth of the volume of air taken up by the rusting wire.

Now let us pass to the burning of a body. If we burn, in a confined volume of air, some highly combustible substance, such as phosphorus or sulphur, the same thing takes place. The phosphorus goes on burning, and as it burns the volume of air gets less and less, until exactly one-fifth of it has disappeared, and as soon

as one-fifth is consumed the phosphorus is extinguished; it no longer burns, and we get exactly the same kind of air as in the other case. Of our original five volumes of air, we have four remaining, and in these, metals will no longer rust, combustibles will no longer burn, and animals will no longer breathe. If, instead of burning a highly combustible body like phosphorus, we take one less so, such as a candle, we find that it is extinguished before one-fifth part of the air has been taken up; but if we then introduce some iron wire it will rust, and take up a further portion of the air; and when the iron wire no longer rusts in it we shall find that the quantity of air absorbed by the candle, supplemented by the remaining portion taken up by the rusting of the wire, amounts to exactly a fifth part of the original volume. Again, if we put a bird or a mouse into a vessel of air, it would go on breathing, whilst the air became less and less, but it could not continue until it had entirely taken up the fifth part of the original air. These animals are, in this respect, in the condition of the candle; but if we take some slow breathing animals, such as snails or frogs, and put them into a confined quantity of air, they will do exactly what the burning phosphorus does—they will go on breathing until they have

consumed the fifth part of the volume of the original air, and they will leave four volumes of air of the same character as that left by the burning phosphorus, in which metals will not rust, combustibles will not burn, and animals will not breathe.

Now comes the question—What is the nature of these remaining four volumes of air? Chemical experiments tend to prove that they are of the sort to which the Greek name of *azotic* or lifeless air was given. It was also called by another name, equally long, and far more barbarous—*phlogistic* air. It has also received the name of *nitrogen* gas, and by this name it is now generally known. Here is a bottle of nitrogen; we introduce into it a lighted taper, and it is immediately extinguished.

Now is it possible to recover this one-fifth part of the air which has been absorbed? Yes, it is; and it is interesting to note that the particular experiment by which the composition of air was first ascertained by Lavoisier, is the same which still best serves to exemplify its composition. I have spoken to you about the rust of iron. Chemists are acquainted with a great number of metals, and in particular with that metal which you see in this bulb, and which you know is quicksilver or mercury. It is a very peculiar

metal, and the only one which is in a liquid state at the ordinary temperature. You know that lead, for instance, is solid at the ordinary temperature, but it will become liquid upon being heated, and even iron and gold, when very intensely heated, also become liquid. Mercury, however, is hot enough at common temperatures to exist in the liquid state, and it is the only metal with which chemists are acquainted that is so ([13]). At the ordinary temperature, whether in summer or winter, and in any climate, mercury does not rust. It only rusts when heated, and then it does so very quickly, and maintains just the same sort of action as the iron. As it rusts, it absorbs one measure out of the five measures of air, and we obtain, as the result, a quantity of the rust of mercury, which is a red substance, not unlike the rust of iron. This bottle contains some of it; it was made by rusting mercury in heated air.

There is another point of interest in connection with this rust—if you go on heating it still more strongly ([14]), the mercury which had become converted into rust, makes its appearance again in the original state, and at the same time a quantity of air or gas is given off, the peculiarity of which is, that the amount of gas so evolved is exactly the quantity of air or gas

which the mercury absorbed in rusting; so that if you take five measures of air and heat the mercury in them, and so absorb one measure, and then take the rust of mercury so produced and re-heat it, you recover exactly the one measure of air which the mercury originally absorbed. Here is the experiment arranged in this small tube. I have in the tube some of the rust of mercury. I will heat it rather strongly, and in the course of a little while we shall find that it will break up into the original mercury, and into a certain quantity of air or gas, which, in a few minutes, I will collect in this receiver, in order to ascertain its nature. The substance will take some little time in becoming sufficiently hot, because, after it has attained the temperature at which mercury rusts, it must be heated to a degree beyond, that it may undergo this decomposition into the original mercury and into the gas. [After an interval]—Our decomposition has taken place in the tube. The vital air is now being given off by the action of heat, and in the upper part of the tube we have the mercury in a separated state. I will just show you what is the nature of the air which we have in our tube—even this small quantity will suffice for our purpose. We introduce a match into this vessel, and you see

how very brilliantly it will burn in the vital air from the rust of mercury.

We will now consider what are the properties of this particular kind of air; it has this property—that if you take the one measure which the mercury first absorbed in order to rust, and add it to the four volumes of air that remain, you get exactly the quantity with which you started—viz., five volumes; and more than that, the five volumes so formed are undistinguishable, by any means whatever, from the original air with which we began the experiment. Now you will remember that this nitrogen—this residual air—is a kind in which bodies will not rust, nor combustibles burn, nor animals breathe. The breathing capabilities all lie in the one-fifth part which becomes absorbed. Then comes the question, what name shall we give to this one volume, upon which the breathing power of animals is exercised? It was originally called *vital air*—and formerly all these different kinds of gases were called *airs*; this vital air is now known as *oxygen gas*.

Now, from what we have observed in the experiments, we learn that atmospheric air is a mixture of four volumes of phlogistic, or azotic air, or nitrogen, with one volume of vital air, or oxygen; at any rate, this may

be taken as about the proportion between the two. It is not exactly correct; the actual figures are—79 parts (instead of 80) of nitrogen, and 21 parts (instead of 20) of oxygen, to make up 100 parts of ordinary atmospheric air [15]; this, then, is the composition of the atmosphere.

I will now proceed to direct your attention to some of the properties of oxygen. You will remember that, in my former lecture, I called to your minds the fact that, in addition to ordinary combustibles, such as candles, coals, and gas, chemists are in the habit of regarding different metals as combustible bodies; and I showed you how magnesium and zinc might be burnt in air. Now I wish first to call your attention to the manner in which iron may be burnt in air, and then to the way in which it may be burnt in oxygen.

We will first burn some iron in air, and for this purpose we must employ a current of air, and also have our iron in a very fine state of division—viz., in filings; for you know that iron in a large mass, such as a poker, will not burn in air, but in the state of filings, you will see that it will do so, and with very considerable brilliancy. [Iron filings were showered upon a large flame from a gas blowpipe, and burned

with their well-known star-like effect.] You see that in this way iron may be very readily burnt in ordinary air. Now I want to show the very different manner in which it burns in oxygen gas. When I burnt it in the air, it was in the form of filings, but I can burn it in oxygen in a much larger mass. I take just such a flame as we had in the last experiment; but, instead of it being supplied with a current of air, as the other was, it is supplied with a current of oxygen gas, and in this we will now try to burn a piece of iron. For this purpose, I will take an old knife, and see what will happen. [A portion of the knife-blade was speedily consumed in the flame, and the combustion was attended by copious scintillations.] Well, you see it is very fortunate (if the expression may be allowed in such a case) that our atmosphere does not consist entirely of oxygen; for if once these knives got thus heated, they would burn almost entirely away, and we should have none for use.

I will now endeavour to burn another metal in oxygen, and it is one with which you are not quite so familiar. There is a piece of metal in this tube; I apply heat to the tube, and the metal will very soon be hot; you will then see it burn in the oxygen gas which I

now pass through the tube. We will have the lights lowered that you may see the very beautiful appearance it presents. It is just beginning to take fire, and now you see it burning with great brilliancy. The metal upon which we are experimenting is arsenic, and by burning it we have produced a compound of the metal with the oxygen in which it burned, and this compound is oxide of arsenic, or the ordinary white arsenic of the shops. Having burnt this substance—arsenic—I am going to do the same with charcoal. [The charcoal was first ignited, and a stream of oxygen was then turned on to it.] You remember that when charcoal burns in oxygen it forms carbonic gas, and this carbonic gas is an oxide of carbon, just as the white arsenic, which we formed by burning arsenic in oxygen, was an oxide of arsenic.

Now, if instead of burning the charcoal in oxygen, I burnt it in the white arsenic, the oxygen would leave the arsenic in order to burn the charcoal. The charcoal is burnt into carbonic gas, and the white arsenic is correspondingly unburnt into metallic arsenic. Here is the experiment already performed. I had here a mixture of white arsenic and charcoal; the charcoal took away the oxygen from the arsenic, and burned

in that oxygen, consequently the arsenic is deposited in a metallic state in the form of this black ring.

I will now show you the combustion of one other metal in oxygen—sodium—and while it is burning I will again have the gas-lights lowered, and ask you to look at the appearance which the various colours upon this diagram exhibit when they are illuminated by the sodium light; and now compare the appearance of those colours under the sodium light, with their present aspect in the bright light afforded by the burning of the metal magnesium ([16]). Now, when the sodium burns in oxygen it forms soda, or oxide of sodium; what then takes place with the sodium, when instead of burning in pure oxygen, it burns in carbonic gas? Just what I showed you in the first lecture. It burns in the oxygen which is already combined with the carbon; it takes away the oxygen from the carbon, thus setting it free, just as when the charcoal burnt in the oxide of arsenic, it took away the oxygen, and set free the arsenic in the metallic state.

Now, carbon may exist in two states—in that in which it will burn, and in that in which it is already burnt. All our ordinary combustibles contain charcoal, but many of them—almost all indeed—also contain another substance. We

know that these substances contain charcoal, because when they burn they give rise to burnt or oxidised charcoal—that is to say, to carbonic gas; but there is another combustible called hydrogen, which is the gas known as inflammable air, and when this hydrogen burns it produces oxide of hydrogen instead of oxide of carbon, and oxide of hydrogen is water. Here is dry hydrogen gas burning, and here is the water which is being produced by its combustion, and when, by means of magnesium wire, I illuminate the jar, you see what a very beautiful appearance is presented by the drops of water on the sides of the glass vessel in which the combustion of the hydrogen has been going on ([17]). Well, then, as I have said, when carbon burns we get carbonic gas or oxide of carbon, and when hydrogen burns we get water or moisture produced, that water being an oxide of hydrogen; and we recognise the presence of carbon or hydrogen in a combustible by the fact that, when burning, the one produces carbonic gas and the other water. Now, I will show you once again the production of this carbonic gas by the combustion of charcoal. I take our old test, the lime-water, and pour some of it into this glass; I then allow the air which has passed over the burning charcoal to bubble

through the lime-water, and as carbonic gas is produced our lime-water turns milky. Now, instead of the current of air which I am using, I will turn a current of oxygen upon the burning charcoal, and you will see that it will then burn in a very different manner. [The experiment was performed, and the formation of carbonic gas by the combustion of the charcoal in oxygen was indicated by the clouding of the lime-water.] In this way you see that, whether we burn charcoal in oxygen or in air, the production of carbonic gas always accompanies the burning.

Now let us turn our attention to some ordinary combustibles. I will first burn some ordinary coal gas from this burner, and notice what products will be furnished by it. To begin, I will take a bottle, at present containing nothing but air, and hold it over our flame; now observe what takes place. You will first of all see that the interior of the vessel very quickly becomes dimmed or dewed with a film of water. Accordingly, coal gas by its burning produces water or oxide of hydrogen; hence we learn that the unburnt coal gas contains hydrogen. Now, does the burning of coal gas also produce carbonic acid? We shall very soon ascertain this by pouring into the bottle some lime-water,

shaking it up for a minute or two, and then observing whether we convert our clear dissolved lime into insoluble chalk. [The lime-water test was applied as described.] You see that in this case chalk is produced, which shows that our coal gas contains charcoal.

As we have talked about coal gas in this way, I ought to call your attention to the manner of collecting it, and show you what sort of a substance it looks like when we get it in something like a definite quantity. I have a tube attached to the gas pipes, and from the end which is under water, you see gas is bubbling up, and is quite invisible. In a minute or two a jar full will be collected. It has all the appearance of ordinary air; it is quite invisible, and nobody can tell from its appearance that it contains charcoal any more than you could detect the charcoal in the atmospheric air by which we are surrounded. Our cylinder is now filled with this ordinary coal gas, and I will proceed to set fire to it. You see the very rapid manner in which it burns when it is ignited in this way.

We will next see how a candle behaves when burnt in a current of oxygen; and I am now going to call your attention to a somewhat different phenomenon. We place a lighted

candle in this glass vessel, and then turn on the oxygen ; the candle is now burning in a current of oxygen. Whilst it is doing so, I will cut off the supply of the ordinary air which is also being admitted to the vessel ; but you see that this does not matter in the least while the candle is supplied with a current of oxygen gas. When, however, I remove the current of oxygen, and allow the candle to burn by the aid of the ordinary air, you see a great difference ; it burns very dimly, and also smokes, and in the course of a minute or two it will go out. Now how is it that the candle smokes in this way? I can make coal gas do the same, and all that is needed to produce this effect is to treat it much in the same way—to cut off the supply of air. If I do this we find that the coal gas also will smoke. Here it is burning in the ordinary way, and now if I bring down a piece of wire gauze upon it, and cut off the supply of air thus, you observe that we get a very considerable amount of smoke.

Now, how is it that when the supply of air is cut off, the burning candle and the coal gas both deposit their carbon in the form of charcoal instead of yielding it in the shape of carbonic gas? Well, I will just direct your attention to the manner in which these ordinary combustibles

burn in another gas, namely, chlorine—this green air, one of the properties of which is that while hydrogen burns in it very readily, carbon or charcoal does not burn in it at all; and, accordingly, if we introduce a lighted taper into it, the hydrogen of the taper burns readily, but the carbon of the taper will not burn, and therefore the flame smokes very much. You see the taper continues burning when it is introduced into the gas, but the carbon which will not burn is liberated, and appears in the form of smoke, instead of being converted into invisible carbonic gas. Here is a jar containing some chlorine, to which I will add some of the coal gas, and we will now set fire to the mixture. [A light was applied to the jar, and the mixture exploded with a sharp detonation.] You see the very vigorous manner in which coal gas burns in chlorine; but you will also observe that the sides of the jar are covered with an abundant deposit of unburnt charcoal. When these *hydrocarbon* substances burn in a sufficient supply of air, both the carbon and the hydrogen burn. The hydrogen is converted into water and the carbon into carbonic gas; but when these substances burn in chlorine instead of in air, only the hydrogen burns, and the carbon, instead of passing into the burnt condition and becoming carbonic gas,

makes its appearance in an unburnt condition as soot.

Again, if instead of burning the candle or the coal gas with a sufficient supply of air, we burn it with an insufficient quantity, the oxygen takes the hydrogen in preference, and this alone burns, the carbon being deposited without combustion. When we were burning this candle in oxygen, both the hydrogen and the carbon burned, and there was no deposit of soot or charcoal; but when the charcoal burned in an insufficient supply of air, the hydrogen and carbon could not both undergo combustion: either the hydrogen alone must burn, or the carbon alone, and the former did so in preference to the carbon. Now, it is in this way that we generally obtain charcoal. Instead of burning the pieces of wood or materials from which charcoal is derived, with a sufficient supply of air, we burn them in an insufficient quantity, and, in that case, the hydrogen undergoes combustion, and the carbon is left unburnt. Some very beautiful forms are frequently obtained in this process. Here is some straw which was burnt in the manner I have described. The hydrogen has been consumed, and the charcoal of the straw remains in this beautiful form. Here, again, are some

nuts and kernels of fruit which have been burnt into charcoal, and in the same way we obtain wood charcoal and the numerous varieties of this substance which are familiar to us. Sufficient air to burn the hydrogen is admitted, but there is not enough to combine with the carbon, and thus we get it in a separate state. There is another way in which charcoal may be obtained. At a sufficiently high temperature the hydrogen separates from the carbon without burning, and this furnishes us with another means of obtaining charcoal. In consequence of the heat which we applied to the tube of porcelain to which I drew your attention in the early part of the lecture [page 60], the coal gas which has been passing through the tube has deposited a large quantity of charcoal on the white porcelain.

So much for the methods of obtaining charcoal. We must now pass on to the consideration of some of the properties of charcoal, and the most remarkable is its extreme porosity. An ordinary piece of this substance, such as that lying on the table, has the singular property of being able to absorb very many times its volume of gas or air, and accordingly we find that what looks like a piece of charcoal, pure and simple, contains many times its own bulk of air. I can show you this by means of the air-pump. If

we place some charcoal in water under the glass of the pump, and then exhaust the air, you will see bubbles of gas given off. Here we have a piece of charcoal immersed in water, and on working the pump we can extract the air contained in the charcoal. [The piece of charcoal was subjected to the experiment described, and gave rise to an abundant stream of bubbles when the pump was worked.] You see the large quantity of air which has been taken up by this piece of charcoal.

Now charcoal does not absorb all kinds of air with the same facility, but it absorbs some kinds far more readily than others. Here is a table showing you the absorption which one kind of charcoal will effect in respect to different gases :—

ABSORPTIONS OF GAS BY 1 CUBIC INCH OF COCOA-NUT SHELL CHARCOAL.

Oxygen	18 cubic inches
Carbonic gas	68 „
Sulphuretted hydrogen ..	100 „
Ammonia gas	170 „

A cubic inch of charcoal will absorb various quantities of different sorts of gas ; but some kinds of charcoal absorb gas far more readily than others, and this is particularly the case with that obtained from the shell of the ordinary cocoa-nut. Let us consider what is the

amount of gas which this form of charcoal will absorb. A cubic inch of the cocoa-nut shell charcoal can absorb 18 cubic inches of oxygen; it is, in fact, capable of absorbing the quantity of oxygen represented by this block. [The lecturer here took a piece of charcoal 1 cubic inch in size, and placed upon it a rod of deal, 1 inch square and 18 inches long. In the subsequent illustrations, rods 68 inches, 100 inches, and 170 inches long respectively, were employed to illustrate the quantities of carbonic gas, sulphuretted hydrogen, and ammonia gas absorbed by 1 cubic inch of charcoal.] Now you can scarcely form any idea of the amount of force which is required for that absorption. If we were to take 2 cubic inches of oxygen, and endeavour to compress them into the space of one, we should require the pressure of 15 lbs. weight; but to compress 18 cubic inches of oxygen into the space of 1 cubic inch, we should require eighteen times 15 lbs., which would be equivalent to about two hundredweights and a half. Here is a half hundredweight, and it is almost as much as I can lift. Now we should require about five such half hundredweights to compress 18 cubic inches of oxygen into the space of 1 cubic inch. But you must observe that the cubic inch of charcoal, which can absorb

these 18 cubic inches of oxygen, appears to be already full of the substance of the charcoal itself; there seems to be scarcely any space left; and what gas the charcoal will contain must occupy its pores. Now, if we imagine that the pores occupy even as much as a twentieth part of the whole mass, we should then require, not five times, but about one hundred times the pressure of this half hundred-weight, to compress 18 cubic inches of oxygen into a cubic inch of charcoal. Nevertheless, so great is the absorptive power of this kind of charcoal, that it gradually exerts upon the oxygen a compressing effect equal to the force of some 50 hundredweights.

With regard to carbonic gas, it has been found that a cubic inch of charcoal is capable of absorbing 68 cubic inches of carbonic gas, or the quantity represented by this rod [placing a rod 68 inches long on the cubic inch of charcoal]. Lastly, there are two gases which are the result of the decomposition of animal matter. When animals undergo decomposition they emit two kinds of gas—one called sulphuretted hydrogen, the other ammonia. Now charcoal has the property of fixing these two gases with still greater facility; and accordingly our 1 cubic inch of charcoal can

absorb 100 cubic inches of sulphuretted hydrogen gas, or the quantity which is represented by this rod ; and with ammonia gas, the power of absorption is even more striking : 1 cubic inch of charcoal is able to absorb 170 cubic inches of ammonia, or the quantity represented by this other rod. You must remember that these gases are not merely compressed into 1 cubic inch of space, but into the small pores or interstices contained in the charcoal, which seems to be solid. Thus you may form some idea of the immense force which charcoal is capable of exerting in this way.

Let me give you one or two illustrations of this property. I have, in this tube, some ammonia gas, and into this ammonia gas I will put a piece of charcoal. This is placed over mercury, and you will see that after a little while, the charcoal will gradually rise in the tube, so as to absorb the whole of the gas, and the mercury will follow it, until the tube becomes completely full.

It is upon this remarkable absorption of different gases by charcoal that the efficacy of this substance as a respirator or ventilator dedepends, for it is found that when these gases are absorbed into charcoal, they have the property of acting upon one another with considerably

increased activity. A striking illustration of this is afforded by the following experiment:—Here I have a glass jar, in the lower part of which is a partridge,—and I am afraid to tell you how long that partridge has been there, but at this time it is in anything but a pleasant condition. On the top of the jar is a piece of iron trellis, and on that trellis is placed some charcoal. If any one who is curious will try to smell the partridge through the charcoal, he will utterly fail to detect any odour; but not only are the offensive emanations given off from the partridge—the sulphuretted hydrogen and ammonia—wholly absorbed by the charcoal, but it also absorbs the oxygen gas from the air, and these gases—the oxygen of the air, the sulphuretted hydrogen, and ammonia—at once react upon one another. The gases arising from the partridge are burned or destroyed through the presence of the oxygen, and accordingly this action would go on for any length of time. Now, for the accommodation of any one who is still curious, there is an opening closed with a cork in the side of the jar underneath the charcoal, and if he wishes to ascertain the difference between the gases before they pass through the charcoal, and after they have done so, there is an opportunity for him to gratify his curiosity.

The same kind of reaction which enables charcoal to behave so excellently as a purifying substance, also renders it valuable as a decolourising agent. Here we have two columns of charcoal, —the charcoal obtained from bone—and I want to call your attention to the decolourising effect it will produce. I have here two coloured liquids, which I will pass through these columns of charcoal, and in order that you may see what change takes place, I will take two glasses of each liquid, and reserve one glass of each, to enable you to see what change is produced in the liquids by their passage through the charcoal. One of these liquids is blue indigo, and the other cochineal. I will now pour one glass of each slowly through the charcoal, for the decolourising action is one which, like the absorption of the ammonia gas, takes a little time for its accomplishment. The result will be, either that the colour will entirely go, or it will be diminished to such a degree that you will see a very great difference in the appearance of the liquids as they run out of the charcoal. [The filtered liquids, after passing through the charcoal, were exhibited to the audience, and found to be deprived of their colour by the filtration.]

Now, in the minute or two that remains to me I will direct your attention to the use of

charcoal in charcoal filters. You see on the table two glasses of water ; one of these is the water supplied to this Institution. This is, perhaps, hardly a fair sample, because, after these heavy rains, it is far more impure than usual. Here is some of the same water after it has passed through this filter, which is filled with animal charcoal, much in the same way as those in which we filtered the coloured liquids. Here are specimens of the filtered and unfiltered water, so placed that you can see with one eye through each tube at the same time, and you will see at a glance what a great improvement the filtration has effected.

LECTURE IV.

CARBON—CARBONIC GAS, OR FIXED AIR.

YOU will remember that ordinary atmospheric air is a mixture of two different kinds, formerly called vital and non-vital air,—or rather, instead of saying "non-vital," chemists used the word *azotic*, derived from the Greek. Vital air is now called *oxygen*, and the azotic is called *nitrogen*. When bodies burn in air they combine with the oxygen of the air, or, in other words, become oxidised, so that when you say a body is burnt in air, it is almost the same thing as saying that it is oxidised, for the fact of its being burnt implies that it becomes oxidised. Now, all the ordinary substances which we are in the habit of burning for the sake of getting either light or heat, consist substantially of carbon and hydrogen, though these do not form their exclusive constituents, as they frequently contain other elements as well. The carbon and hydrogen are in

an unburnt or substantially unoxidised condition. This candle, for example, although it is perfectly white, contains a very large amount of carbon; and there is nothing more remarkable in the white candle containing carbon, than there is in the white marble containing it. The only point of difference is, that, in the marble, the carbon is already oxidised or burnt, and in the candle it is not. When we light a candle we oxidise or burn its carbon, and we get its oxidised hydrogen in the form of water, and its oxidised carbon in the form of carbonic gas. When a candle is burnt with a sufficient amount of air, so as thoroughly to consume its constituents, we get nothing but these two products. Here is a bottle in which a candle has burned; the sides of the vessel are covered with moisture which has been formed in the burning, and on pouring some lime-water into the bottle, and shaking it up, it is converted into a mixture of chalk and water, by the carbonic gas which has been formed in the bottle by the combustion of the carbon of the candle. When, however, there is not enough air or oxygen to combine with both the carbon and the hydrogen of the burning candle, one of them must, in familiar language, "go to the wall," and it is the carbon which does so. The hydrogen is burnt first, the

oxygen having a preference for it, and the candle deposits its carbon in the form of soot. Now, this is an illustration of the way in which nearly all the varieties of charcoal are made. The materials are burnt with an insufficient supply of air—enough to burn the hydrogen and not the carbon—and accordingly the carbon is deposited. Those large masses of coke which you see behind the locomotive engines, are obtained in a similar manner. The coke consists of the carbon of the coal, the hydrogen being burnt away in the process of manufacture. In the same way, charcoal is got from wood by burning off the hydrogen and leaving the carbon unburnt; but there is altogether a different method by which the carbon may be separated from the hydrogen, and I mentioned it in my last lecture. Coal gas, you know, although perfectly transparent, contains black carbon, and when this coal gas is burnt with an insufficient supply of air, we get soot by our old process (I call it *old* because of my having already spoken of it); but if, instead of burning the coal gas in that way, we make it very hot, under such circumstances that, through the exclusion of air, neither the carbon nor the hydrogen gets burnt, these constituents become separated from each other. Here is the tube containing the white porcelain, which,

during the last lecture, we subjected to a strong heat while the coal gas was passing through it (page 60). The blackening of this white porcelain indicates that the carbon of the coal gas has been separated from the hydrogen, and the separation occurred, in this case, not from the effect of imperfect burning, but through the application of a strong heat. This, then, is another mode in which carbon may be obtained from its combinations. That large piece of carbon in front of you is called *gas carbon*, and it was made in the same way as that in the tube—by subjecting ordinary coal gas to a sufficiently high temperature. That carbon ought to have remained in the coal gas, but it was separated from it, and lined the interior of the vessel, when the hydrogen passed on and left it.

Having spoken of the different ways in which carbon may be separated, I will just call your attention to an experiment which shows the actual preparation of it. I have here a small platinum dish, in which I have placed some substances capable of being burnt; these are nothing but nuts, kernels of fruit, acorns, and so on. If I simply burn them, they will all go away, and nothing will be left of them; but if, before making them hot in the dish, I take the precaution to cover them with sand, so that they

get a very small supply of air, then they will burn imperfectly, and at the end of the lecture we shall have a residue in the form of charcoal. I am applying a good strong heat, and, in a little while, the hydrogen gas will escape from the top of the sand, and there ignite. You will see the hydrogen and a portion of the carbon burning, but the great mass of the carbon will remain behind, and we shall find it, at the close of the lecture, much in the same form as you see these nuts and kernels in this glass, converted into charcoal. [Later in the lecture the gases driven off by the heat from the contents of the platinum dish were observed to be burning on the surface of the sand].

So much for the way in which carbon is obtained; now for its properties. You will recollect that in the last lecture I called your attention to its very remarkable effects in absorbing gas. When you take a piece of charcoal into your hand, you not only have the carbon there, but you have also a large quantity of air or gas condensed in the pores of that carbon. In our last lecture, by means of an experiment with the air-pump, I showed you the charcoal giving up the air which had been contained in its pores. That was an illustration of the mode of extracting the air from the charcoal. Now I want to show you

the way in which we can get air *into* the charcoal. In this case, the air we will take is ammonia. I performed the experiment during the last lecture (page 81), and I will now repeat it. You see that the charcoal is gradually absorbing the ammonia gas, and, as it does so, the mercury rapidly rises.

There are some other curious properties of this charcoal to which I briefly alluded in my last lecture, and about which I wish now to make some further remarks. You will recollect my telling you that the gases given off by the partridge, undergoing the change called putrefaction, are absorbed into the charcoal; but they are something more than absorbed—they are *destroyed*. They are slowly burnt or oxidised—for you will remember that burning is another word for oxidation. The charcoal absorbs not only the gases given off by the partridge, but also these atmospheric gases, and these latter, when they come into contact with the gases given off by the partridge, which are, particularly, sulphuretted hydrogen and ammonia, destroy them by oxidation. Now, this sulphuretted hydrogen gas which is emitted by putrefaction, has an exceedingly objectionable smell, and this smell affords one of the most delicate means of recognising its presence; but, fortunately, there are

other ways of detecting it. It has the property of affecting certain metals, and when we want to ascertain whether this gas is present, we are not obliged to resort to the unpleasant method of smelling it. In this glass jar I have some paper which has been prepared with a metallic solution ([18]), and I will cause a current of sulphuretted hydrogen gas to pass through the tube into the jar or cylinder, and you will notice, I think, in the course of a little while, that our test paper inside the cylinder, indicates to us the presence of the gas, just as effectively as its smell would do, if we put our noses to the vessel. You see that the letters gradually come out on the test paper; they have now become perfectly visible. Thus we are able to recognise this gas, not only by its smell, but by its action on the paper. I have here a tube which brings me a current of ordinary air, worked from a bellows below. This current bubbles up through a solution containing sulphuretted hydrogen, and, in so doing, it takes some of the sulphuretted hydrogen with it; it then goes into this glass vessel, when the sulphuretted hydrogen affects our test paper, and the air escapes from the top of the jar. If it escaped direct into the theatre, the sulphuretted hydrogen would be smelt by you; but I place over the top of the jar some

pieces of wood charcoal, which absorb the sulphuretted hydrogen, and destroy its smell. We will now try the action of this gas on another kind of test paper, and here the effects will be somewhat similar to those produced in the last experiment, only, in this case, I have no letters written upon the paper. We will pass the gas through this other cylinder containing test paper, and you will see what effect it has there. In this case, the paper, instead of being written over with letters formed by a test solution, has been steeped in different solutions, and accordingly a very much larger quantity of gas is necessary to colour the whole of the surface. You see the paper is now becoming coloured; first we have the action of the gas upon a salt of lead, as shown by the production of a black mark. As the gas rises higher and higher, you see it begins to effect the next solution on the paper, and in this case, instead of a black stain, we get an orange one, and I daresay, after a little while, another colour will be developed at the top. I may call your attention to the bottom of the paper becoming yellow. The colour at the top is now appearing, and at the risk even of getting a slight smell from unabsorbed sulphuretted hydrogen, we will allow the action to go on to the full extent.

I want now to illustrate to you the mode in which charcoal arrests the flow of this gas, and for this purpose I will here take some small glass cylinders, containing metallic solutions upon which sulphuretted hydrogen will act, and I am going to blow through these solutions, the same kind of sulphuretted air that I blew into these larger cylinders a few minutes ago ; but I will arrange the experiment in such a way that, before the air bubbles up into the water, I can either let it pass through the charcoal or not, at will. I am afraid that in this case I cannot keep back the odour, but I will endeavour to do so as much as I can. Here is one pair of cylinders, and the gas which passes through them must, first of all, go through the charcoal; but, in order to pass through the other pair of cylinders, it need not do so. We will first of all let it go through these cylinders where there is no charcoal, and then see what are its effects. The gas now enters our solutions, and immediately produces, in the one case, a purple colouration, and, in the other, a decided orange ([19]). This is caused by the gas itself, before it has gone through the charcoal. Now we will let it come up from the other cylinders ; in this case, it has first of all to go through the charcoal, and you will see that after it has done this,

it has no action whatever upon the solutions. It is now bubbling up through these solutions in the same way as it did through the others, but here we get no action. The charcoal completely arrests the passage of the gas, and not only arrests it in the way of absorbing it, but entirely destroys it. In this instance, we are passing the two gases, sulphuretted hydrogen and oxygen, into the charcoal, and they immediately react upon one another in the pores of the charcoal. In order to show you that the want of effect does not arise from any exhaustion of our sulphuretted hydrogen, we will now let it ascend through these new vessels, without passing through the charcoal, and you see that the solution on my left very quickly becomes orange in colour, and that on my right becomes purple. Thus, the want of action was not due to a deficient supply of sulphuretted gas, but was merely owing to the fact that, as the gas passed through this tube containing charcoal, it was so completely absorbed and oxidised that it could not, in any way, affect the solution through which it afterwards bubbled.

With regard to the action of charcoal upon liquids, you will remember that, on the last occasion (page 83), we had two columns through which we filtered a red and a blue liquid, both of which

had their colours completely taken out. I ought to call your attention to some of the practical applications of this property of charcoal. Here are some specimens of Madeira, Demerara, and beet-root sugar, which have been kindly supplied to me by Mr. Duncan, of Whitechapel. The whole of the colour of these liquids has been taken out by filtering them through charcoal, in the way that you saw me filter the liquids the other day. After the first filtration, we get a liquid which has a distinctly brown tinge when compared with the white sugar, but after a second filtration through charcoal, the liquid, on evaporation, yields pure white sugar.

Now, in all those changes to which I have called your attention, the charcoal itself remains the same. We have next to consider more distinctly the changes which charcoal undergoes, apart from those which it is capable of producing upon other bodies.

Charcoal is a very stable body. It lasts for ages and ages, and is not liable to decay. In the British Museum there are specimens of charcoal which were charred at Pompeii, and which have stood for centuries. It is one of the most stable bodies we know; nevertheless, it is capable of being acted upon by strong chemical re-agents. I will take some of this

substance, and act upon it by an acid. I must have my charcoal rather warm for this purpose, and now I let it fall into this strong chemical agent—nitric acid—and you see that, under these circumstances, the nitric acid acts upon it very violently ([20]). The charcoal, which is a very permanent body, and not affected by most chemical agents at ordinary temperatures, is acted upon by this nitric acid, and to such an extent that it not unfrequently takes fire, as in this experiment.

The most important, however, of the changes which it is capable of undergoing, is one to which I have already, on one or two occasions, directed your attention, namely, its change into carbonic gas, and now I will once more show you this change, but in a somewhat different form. I have here a piece of easily igniting charcoal enclosed in this tube; I just set fire to it at one end, and place it alight in the tube, through which I pass a current of oxygen gas. You observe that the charcoal is now burning with very great brilliancy in the oxygen gas. The charcoal is converted into a gas, and as it bubbles up through our lime-water, it changes the lime-water into a mixture of chalk and water. In this way, I cause the complete disappearance of the charcoal, it being con-

verted entirely into carbonic gas, which I am arresting by means of the lime-water. Here you see the large amount of chalk which I have produced by the conversion of our charcoal into carbonic gas, and the combination of that carbonic gas with the lime contained in the lime-water.

I will now illustrate the conversion of charcoal into carbonic gas in one or two other ways. I will bring before you another mode by which we may burn this substance in oxygen. You observe I am burning some in a globe full of this gas, and it is ceasing to be charcoal, and is being changed into carbonic gas; and here you have an illustration of the most remarkable, or, at any rate, the most important of the changes which charcoal is capable of undergoing. Lastly, I will show you one more experiment illustrating the mode in which we can burn charcoal in oxygen. [A stream of oxygen was made to impinge upon some pieces of incandescent charcoal, lying at the bottom of a glass beaker]. You see the very brilliant manner in which the charcoal burns in our current of oxygen gas.

We have, then, arrived at this point—that charcoal is a substance which burns very readily, and, by its combustion, is converted into carbonic gas.

[illegible]

[illegible] Here I have such an apparatus, in which carbonic gas is being produced from marble, and from which I can obtain it in order to consider its properties minutely and in order. I first turn on our gas, and immediately we recognise one of its characters, namely, that it has the property of combining with soluble lime, and of converting it into insoluble chalk. The next property of the gas which I shall show you, is also one to which I have before alluded—its property

of extinguishing flame. Here is a large glass jar which has been filled with carbonic gas from an apparatus beneath this theatre, similar to the one on the table, but which is on a larger scale, and supplies us more conveniently with the gas. We will see whether this glass jar is full of the gas. [A lighted taper was extinguished immediately upon being introduced within the brim of the jar.] Yes, it is quite filled. You see, directly I put the taper in, it is extinguished. If I take some larger substance—this burning tow, for instance—it also is completely extinguished. The second property of carbonic gas, then, is that of putting out flame.

I wish now to make you acquainted with some further properties of this gas; I will first show you what its behaviour is under certain circumstances, and then I can remark upon it after you have seen the experiments. Here is a long tube filled with water, with its open end immersed in the same fluid. I will raise the mouth of the tube a little, and fill it to the label with carbonic gas; I take the tube and shake it up with the water, and then notice whether any effect is observable. I keep it closed firmly with my hand, and replace the mouth in water; on removing my hand, you see that the liquid rises very considerably in the

tube. This experiment, then, reveals to us the fact that carbonic gas is capable of being absorbed in water. It is appreciably soluble in water through this agitation, but it will dissolve to a much greater extent under pressure ([21]). The experiment is rather too long for me to show it to you as a lecture experiment, but I will explain to you its result. If I took a bottle of ordinary water, and applied this forcing syringe to it, I could inject into that water a large quantity of carbonic gas—a quantity, indeed, only limited by the strength of the bottle. I could go on forcing in the gas until I burst the bottle. Here is a bottle of soda-water, which I have made by pumping carbonic gas into ordinary water, and, in fact, most of the soda-water ordinarily met with is made in this way. On removing the pressure from the surface of the liquid, the gas escapes, and this gas which is given off is nothing more than that which is obtained from marble or burning charcoal, and it has all the properties which I have mentioned as belonging to carbonic gas. You will remember that the gas from marble has the property of extinguishing flame and of making lime-water turbid. I will collect some of the gas evolved from soda-water, and I will then show you its properties. Here, for example, is

a bottle of soda-water; I open it in the usual way, but cautiously, so that the gas may not escape very violently. Having removed the cork, I let the gas from the soda-water play upon the flame of a candle, and you see it at once puts it out. Now let me show you the amount of gas which we can collect from a bottle of soda-water. I take a cylinder of water, close it with a glass plate, and invert in a pneumatic trough. Here is a bottle of soda-water, into which I have inserted a tap; this I turn on, and allow the escaping carbonic gas to pass through a tube and bubble up through the water into the glass cylinder, and in this way I can collect a considerable quantity of this gas. Now, let me show you that this soda-water gas is capable of giving a precipitate with lime-water. I take another bottle of it, but instead of using a screw-tap, which is not necessary for the present experiment, I remove the cork in the ordinary way, and quickly insert in its stead a cork fitted with a glass tube, which has been placed in a hole bored through the cork. The gas which escapes from the liquid in the bottle passes through this tube, and we now have the gas bubbling up through the lime-water test, and converting it into chalk and water, just as did the gas we obtained in other ways.

This gas has another very important property; instead of using the ordinary strong lime-water I will take some far more dilute. I have put some of the strong lime-water into this jar, and now I will add to it a considerable quantity of distilled water. Here, then, is our diluted lime-water, and I now pass a current of carbonic gas rather quickly through this solution. The first effect in this case, as on previous occasions, is that we get our deposit of chalk, but I want you to watch the experiment, for you will find that the chalk, which at first is thrown down, entirely disappears after a little time. I can show you the same result in the case of soda-water. I will pour some lime-water into another of these glasses, and then empty into it a bottle of soda-water, and watch the result. You observe the first effect is that the lime is converted into chalk, of which we obtain a considerable amount. Now I will add some more soda-water, and you will observe that the liquid becomes perfectly clear. Here, again, is another liquid in which chalk has been formed by the action of carbonic gas upon lime water. It is perfectly opaque, but if we add a little soda-water to it, the precipitate of chalk will eventually disappear. We have thus learned a fact entirely new to us—namely, that although, when we add carbonic

gas to lime-water, we get insoluble chalk, yet if we continue to pass the carbonic gas through the chalky liquid, the whole of that chalk entirely dissolves after a certain length of time; so, while chalk is insoluble in pure water, it is perfectly soluble in water containing carbonic gas. Indeed, all our ordinary waters have chalk in solution, held dissolved by means of the gas obtainable from charcoal.

Another fact with regard to the solubility of this gas in water is that, when we remove the pressure—that is to say, take the cork out of the soda-water bottle—we allow the escape of a considerable quantity of this gas, but we do not expel the whole of it. In order to do this, we shall find it advisable to boil the water. In this flask we will boil some water containing carbonic gas. This is a bottle of soda-water, from which we allowed all the gas to escape which would do so upon merely uncorking the bottle, and as the escape has gone on to that point, we will allow the water to boil in the flask, or rather we will apply heat to it, and you will find that the heat will drive off more of the gas, and in the course of a minute or two, we shall collect in in a cylinder. I will allow it to heat rather rapidly, and you will see the gas bubbling up through the cylinder. You observe we are

now driving off more of the gas by the application of heat. Now, just bear in mind what would happen if I took the cylinder and boiled the liquid containing the chalk, which was dissolved by the presence of carbonic gas in the water. The heat would drive off the excess of carbonic gas, just as we are forcing the carbonic gas off from the liquid in the flask. We ought consequently to have our precipitate of chalk manifesting itself in the solution; this is just what happens. We will boil that liquid, and you will see that when this is done it will deposit chalk on giving up its carbonic gas. [After an interval]—I will now ask you again to observe this liquid. You remember it was at first perfectly clear, but on boiling it has become opaque. The chalk, which was held in solution by the carbonic gas, has been precipitated as the gas became driven off by the heat. That deposit is nothing but boiler fur. Now, this [exhibiting a large broken kettle considerably furred inside] is not a very elegant article to bring before a Royal Institution audience; this kettle contains a large quantity of *fur*, consisting of the chalk which was dissolved in the water by the carbonic gas, and deposited on the inner surface of the kettle, when the carbonic gas was driven from the water by boiling.

Chemically, this deposit is nothing more than marble [22]. If I take a portion of this boiler fur and act upon it by heat, carbonic gas will be evolved, or, if I add acid, it effervesces very readily, and gives rise to the same gas.

We have now collected a rather large quantity of gas by boiling the soda-water. We will just ascertain whether this gas possesses the property of extinguishing flame. [A light was lowered into the jar containing the collected gas]. You see from this experiment that it *does*; thus, partly by merely removing the cork of the soda-water bottle, and collecting the escaping gas, partly by boiling the liquid, you see that we have procured a large quantity of carbonic gas, of which I will now exhibit to you some other remarkable properties. I have here a bottle containing gas; I take out the stopper, and still we have the bottle of gas. I will test its presence in the usual way, by introducing a lighted taper; the taper is at once extinguished, and though the bottle might be left open for a considerable length of time, still the gas would remain and the taper would be put out. Now, what does that suggest to us? Let me try whether I can perform a somewhat similar experiment with a glass of water. I will take this bottle containing a solution of salt. It is nothing

more than common salt dissolved in water, and it is coloured so as to make it visible. Now I lower this bottle into a jar of colourless water: I do it carefully, so that the solution of salt mixes with the water as little as possible, and you see that the coloured solution of salt remains in the bottle, although it is at the bottom of the jar of water. It does not mix with the water to any appreciable extent, because the solution of salt is really heavier than the water above it; and just in the same way this carbonic gas remains in the open bottle, undergoing no very appreciable amount of mixing with the surrounding air, because it is really heavier than the air. I once more introduce the taper, and you see that the bottle still contains the gas, for the taper is extinguished. Now I will reverse the experiment, and take this glass bottle containing a liquid lighter than water—spirit of wine—coloured red. I will lower it into the jar of water, just as I introduced the solution of salt,—but observe the difference of the result! See how the red liquid is streaming up to the top of the jar of water, and the colourless water is pouring into the glass which contained the spirit! Our carbonic gas is, therefore, in the position of this solution of salt, and not in that of the spirit of wine. You see that, introducing in this way the

coloured spirit into the jar of water, I obtain two perfectly distinct layers of liquid. The water is beneath, and the coloured spirit at the top; you see I can draw off some of the latter from the upper part of the vessel.

I can show you some very curious effects of the weight of this carbonic gas, and I have here an experiment arranged for that purpose. In this bottle are two separate gases—carbonic gas and oxygen—the oxygen being in the upper part. I pass this lighted taper rapidly through the oxygen into the carbonic gas, and the flame is immediately extinguished. I raise it into the oxygen, and you see how readily the taper bursts into a flame, and how brilliantly it burns. Thus, you perceive that this carbonic gas is not only heavier than atmospheric air, but it is also heavier than oxygen, which will float on it ([28]). [The taper was extinguished and re-kindled several times in succession by being plunged into the carbonic gas, and then rapidly raised into the stratum of oxygen in the upper part of the bottle.]

I will make use of some liquids to illustrate to you the effects of these differences of weight. In this jar I have merely some water coloured red in order that it may be distinct, and through this water I want to pour a heavy liquid,

namely, a solution of common salt, coloured purple, and by pouring this carefully through the funnel, I shall, in a little while, get a layer of purple liquid at the bottom. There is always a certain amount of mixing, but it will be so little that you will easily recognise the two distinct layers—a purple layer of solution of common salt at the bottom, and a red layer of water on the top. I think those who are near will see that we have already obtained these. I am, in fact, pouring a heavy liquid through a lighter one, and just in the same way I can pour a heavy *gas* through a lighter one, either by means of a funnel, or by another method which I will presently explain to you. If I take a liquid which is much heavier than water, I can pour it into water and form a distinct layer without any funnel. Here is some colourless water, and into this I am about to pour a liquid which is much heavier than the solution of salt, and which may therefore be poured without the funnel. This heavy liquid is oil of vitriol, and you see that in this way we get the colourless water at the top, and a stream of oil of vitriol descending to the bottom, and there forming a shading of blue.

Now I want to illustrate the same point to you by means of experiments performed with

carbonic gas. Here is a cylinder of this gas coloured brown ([24]), and I will pour some of it into this cylinder of air. You will see it pass through the funnel, and reach the bottom of the cylinder. It takes some little time to descend, but I can already see it pouring down. The funnel is now full of the brown gas, and sufficient has descended into the cylinder to answer our purpose. I have thus poured down our heavy carbonic gas, which was coloured brown; but I will now show you that I can not only pour carbonic gas through the funnel, but through the air without a funnel, just as I did the oil of vitriol through the water. I take this bottle of carbonic gas, and let a little of it flow upon the candle, and so put it out. Now I will pour some into this bottle containing lime-water. You observe that the lime-water is perfectly clear; but I now remove the stopper from the bottle of gas, and pour some of it upon the lime-water, and you see that we get an ample precipitate. Let us try the weight of the gas in another way. Here is a pair of scales; you see that, at present, the counterpoise is a little too heavy, and goes down rather lower than the other side of the balance. I now open the bottle of gas and pour some of it carefully into the beaker attached to the scales, and the gas

is so heavy that it actually turns the balance, and not only turns it, but keeps it down to a very considerable degree.

I will now proceed to give some further illustrations of the extreme weight of carbonic gas.

Here is a jar full of carbonic gas, the presence of the gas being shown by the immediate extinction of a lighted taper; the jar is apparently empty, but in reality it is full of gas. If I wanted to empty it of any liquid it might contain, there are several methods to which I might have recourse; of course the most obvious one would be simply to pour it out. I will first see if I can pour anything out of this jar on to the taper. [The jar was tilted over a lighted taper, which was at once extinguished by the invisible gas.] You see we have poured something out. We will try it in another way. Here is a bottle of lime-water, and we will see whether we can pour into it any gas from our jar. I just hold our apparently empty jar over the lime-water, and then shake up the lime-water, and you see it is at once converted into a mixture of chalk and water; this is the most usual way of getting a liquid out of a jar. There is another method, to which we may very easily resort. I will pour

out some of the gas upon the candle in another way; I first pour some of it into a beaker, and then from the beaker on to the candle, which is thus at once extinguished. This is another illustration of the mode of getting this heavy gas out of the jar—by simply pouring it. Now we will adopt some other methods. I again light the candle, and, instead of pouring out the gas, I will bale it out. I take a glass cup, and introduce it into the jar of carbonic gas, thus abstracting a quantity of it, which I will pour from the cup into the lime-water ; I then shake up the lime-water, and you see that I have in this way actually conveyed some of the gas into the bottle of lime-water. Now I will try whether some more of the gas can be baled out from this jar, and a candle extinguished with it. I fill the cup with the gas, and pour it upon the candle; and you see that at once the flame goes out.

If I wanted to empty out of a large jar like this any liquid it might contain, I could, as I have reminded you, pour out the liquid as I did at first, or I could bale it out; but there are other methods still which might be employed. You must all be familiar with the syphon, and you have, no doubt, seen it in use in the streets, in front of public houses, for the purpose of

drawing off spirits from the casks into the large measures. Now let us try whether we can in the same way remove any carbonic gas from this jar; we will first fill our syphon, and then see if we can syphon off the gas. We apply the syphon; and you perceive that, by its means, we can cause the gas to flow upon the candle, and at once put it out. I now take a little lime-water, and upon this I allow the syphon to empty itself for a few instants. [After a short pause]—It has gone on long enough, I have no doubt. I therefore place the stopper in the bottle of lime-water, and, on shaking it up, the lime is immediately converted into chalk. I have syphoned off the gas, and this proves to you that it is heavy, and can be treated like a liquid; we can either pour it out, bale it out, or syphon it out.

Now let me give you one or two further illustrations of the weight of carbonic gas, and for this purpose we will take it as it is contained in soda-water. Here is an empty bottle,—that is to say, a bottle containing nothing but air; I will pour into it some clear lime-water, and then endeavour to act upon that lime-water by the gas evolved from our bottle of soda-water, and at the same time I shall have an opportunity of showing you the weight of the gas. In my last

lecture I once or twice put out a candle by the gas evolved from soda-water, and this experiment I intend to repeat; but this time I will pour the gas upon the candle, and so show you its weight; for when I extinguished the candle by means of the gas from soda-water, we had not considered the weight of the gas. I open the soda-water bottle carefully, and first I will try the action of the gas upon the lime-water. I take a funnel, and into it I pour some of this carbonic gas, that it may descend into the lime-water. I simply pour the gas, without any of the water which is contained in the bottle, and you see that we have formed a reasonable amount of chalk by means of the gas thus poured upon the lime-water. [The lime-water was shaken, and became turbid, indicating the presence of carbonic gas in the bottle.]

Now let me call your attention to another mode of getting out this gas, and for that purpose I will use this larger cylinder, which is now being filled with the gas from the supply down stairs. We will ascertain whether the jar is full: you see it is, for on introducing the taper, the light is at once extinguished. You know that another very common way of emptying a large vessel of water is to use a tap. Now here is our large jar really full of gas, although

it looks as if it were empty. I just close the tap by putting my finger upon it, and I will first draw off a little of the gas over a bottle of lime-water, into which I now let some of it run. I have no doubt that the bottle now contains sufficient for our purpose. I shake it up, and you see we get a similar result to that obtained with the soda-water. I will take another bottle, and this time, instead of allowing the gas to run directly into the bottle, I will let it run into the beaker so as to fill it, and then I will pour its contents into the bottle. I hold the glass beaker carefully under the tap, so as to catch the gas, and now that it is sufficiently full I close the tap with my finger, and pour the gas contained in the beaker into the bottle. I shake up the bottle, and here again you see our clear lime-water is converted into a mixture of chalk and water. I will now allow the gas from the tap of the jar to flow upon a candle, and you see that as it does so, the flame is at once extinguished by it. Here is another candle, upon which I will also let the gas pour down, and I may call your attention at the same time to the force with which it issues from the jar. You see that, in this instance, it blows out the flame of the candle before completely extinguishing it in the usual way. I will now

allow the carbonic gas to fall upon a flame of ordinary coal gas, and in this case also the flame is extinguished. Next I will endeavour to catch some of this gas by pouring it into a beaker, and then try to pour it from the beaker on to a candle. You see the vessel was completely full, for when I pour the gas on to the candle, the flame immediately goes out. I will now give you another illustration of the weight of the gas. In this instance, instead of bringing the candle to our barrel, I will bring the barrel to the candle. Having done so, I remove my finger from the tap, and you see the light is at once entirely extinguished. I will try the same experiment with a gas jet. I bring the barrel of gas to the jet, and when I remove my finger the flame is at once blown out. The fact is, the gas is pouring out from this tap with considerable force, as is proved by its action on the flame. Again, I collect some of the gas in a beaker, and wait until there is reason to believe that the vessel is full. Having now got sufficient gas for our purpose, I empty the beaker on to some lime-water, and on shaking up the lime-water you see that a quantity of chalk is formed.

So much, then, for these illustrations of the way in which this heavy gas may be got from a

vessel by all the ordinary processes that are employed for getting water out of a vessel. I refill our large jar for another purpose. You will remember that at a former lecture I had a cylinder apparently full of only one liquid—water—though in reality it contained two; the lower liquid was water, and the upper one was spirit, floating upon the water. You may perhaps recollect the means by which I ascertained the line of demarcation between the two fluids. I dropped in a piece of wax, which sank through the spirit; but when it came to the surface of the water, it immediately floated upon it, showing us the height to which the water reached. Now I can show you a somewhat similar experiment with the gas in this large jar, and you will see to what height the carbonic gas reaches. Instead of taking a piece of wax, as I did when we were experimenting with the water and spirit, I will take a balloon—one of those toys with which we are all familiar. You see this balloon will not fall very quickly through the air, but still it would fall down to the ground in a moment or two if we allowed it. [A small india-rubber balloon distended with air was placed within a large cylinder, partially filled with carbonic gas. The balloon sank a short distance down the cylinder, and there

floated on the surface of the invisible carbonic gas, indicating the height of the gas in the cylinder.] You see very clearly that the balloon floats on the surface of the carbonic gas, just as the piece of wax did on the surface of the water. If I knock the balloon down through the carbonic gas, it will not keep down, but rises to the surface of the gas. I will give you a final illustration of the weight of this gas, and so bring these experiments to a conclusion. I will now put into the jar another balloon, having previously turned the tap. It will gradually sink, and thereby indicate to us the pouring out of the gas. You will see from the fact of the balloon sinking lower and lower, that the jar is getting more and more empty. The gas from the jar is gradually pouring out into the cylinder below, and this I can prove by inserting a lighted taper into the lower vessel. The taper goes out.

LECTURE V.

GRAPHITE—DIAMOND—SOLID CARBONIC ACID.

IN this lecture I have to bring before you some very important points in reference to carbon or charcoal. You will remember that carbonic gas is oxidised charcoal,—a compound of charcoal or carbon with oxygen. I want now to call your attention to some other compounds of this charcoal or carbon, and one of the most important is that which it forms with iron. If we take a piece of fine iron, such as is used for wire, we shall find that it is either free from carbon, or contains a very minute proportion—not more than one-tenth per cent. How do we know this? We know it because, when wire is burned, it scarcely yields any carbonic gas as a product of its burning, and therefore we conclude that the iron is almost free from carbon; but if we take the same iron and heat it strongly in contact with charcoal, we find,

afterwards, that it has undergone a considerable change. It alters very much in its character; it no longer possesses anything like the toughness it formerly had; it is either very soft or very brittle, according to circumstances, but it has lost the toughness which characterised the piece of pure iron. It has, moreover, acquired another property, namely, when it is burnt, either in air or in oxygen, it yields a very considerable amount of oxidised carbon, or oxide of carbon, or carbonic gas. It has taken up a considerable quantity of charcoal—a quantity which may occasionally amount to 5 or 6 per cent ([25]). It is often, however, 4 per cent of the iron, and we know that it has absorbed this carbon by the alteration in its properties, and more especially by the fact that, when burned, it yields burnt carbon as a product of combustion. Well, this substance which is so produced, differs very remarkably in another way from pure iron; it is readily fusible, whereas pure iron is very difficult indeed to melt, and requires special arrangements for its fusion. We find that this substance, which is obtained by causing wrought-iron to enter into combination with carbon or charcoal, is a tolerably fusible material, so that it may be used for taking the finest castings. It is no longer pure iron, but

a chemical compound of iron and charcoal. Now, when this compound is allowed to melt and cool slowly, it presents a very curious appearance, being covered with a series of scales. Here is a sample, lent me by Mr. Abel, and here is another still more remarkable in its character. When we pick out these scales and examine them, we find that they consist of nothing but carbon; and we ascertain this by the fact, that when burned, they only yield carbonic gas or burnt carbon; so that the carbon which at first went into the iron is separated from it in the form of these scales, and we find that these scales are identical with black-lead or plumbago; in other words, we have converted this ordinary carbon into a substance known as graphite, black-lead, or plumbago.

Now, for some of the properties of this black-lead. It is a crystalline substance, and consists of pure carbon; upon being burned it yields nothing but carbonic gas; it is met with in nature, being found in metalliferous rocks, in Cumberland more particularly, and it is also found in meteorites. Here is a very fine section of a meteorite; it is a piece of iron that has fallen to the surface of the earth—it has fallen at any rate from the skies, and how much further we will not speculate. When we cut a

meteorite in halves and get a section of it, we find that a great part of it is composed of iron; but in addition to the iron, we can pick out pieces of this black-lead, or graphite, or plumbago, such as we can manufacture artificially, in the form of scales, from the compound of charcoal and iron. Here is a piece which has been extracted from a natural mineral. Now this graphite, when burned, yields carbonic gas, which has the property of converting lime-water into chalk and water. To illustrate this, I will take a specimen of powdered plumbago, black-lead, or graphite, and introduce it into a tube, formed of a piece of platinum foil. I put a small quantity of the graphite into the tube, and I light it by means of a piece of ordinary charcoal or pastille. Having ignited the charcoal, I allow a current of oxygen gas to pass over it, and when once the graphite takes fire, you will observe, I think, that it will burn with very considerable brilliancy. The graphite has now ignited, and you see the very brilliant manner in which it burns. It is, then, capable of being burned in this way in a current of oxygen, and, in burning, it produces nothing but this carbonic gas, or oxidised carbon, as its product of combustion, proving that it consists of nothing but, and is identical with,

carbon. Now, this substance, graphite—this form of carbon—has been examined very carefully by Sir Benjamin Brodie, who has found that it has some very curious properties, and to some of these I will direct your attention. If we take charcoal, and act upon it by chlorate of potash and oil of vitriol, the effect is such that it is impossible, by the eye, to distinguish the product from ordinary graphite; but it differs from graphite in the effect heat has upon it. You see the black substance which I have at the bottom of this test tube, covering it to the depth of half an inch or so; upon this I will now try the effect of heat. The action is already taking place, and you observe that the mass is beginning to grow. It is giving off steam, and now this substance, which has been partly acted upon by the acid, and become oxidised, has swollen up to such an extent as to occupy fully two-thirds of the tube, and I have no doubt that, by continuing the heat a little longer, I may be able to push the substance up to the very extremity of the tube. It is still moving upwards, and getting nearer and nearer to my fingers every instant. The tube is now very nearly full; in another moment I shall not be able to hold it,—it will become so hot; and now you see that this black-lead, which formerly occupied a

very small part of the tube, has swollen up and filled it.

Well, what is the nature of this change? It was only ordinary black-lead, which had been acted upon by the mixture; I applied heat to to it, and thereby converted it into the original black-lead with which we started. Now Sir Benjamin Brodie has submitted some of this graphite to the action of very strongly oxidising agents, and has so converted it into a yellowish crystalline substance, which he calls *graphic acid*. I heat some of this graphic acid, which has kindly been supplied for this occasion by Sir Benjamin Brodie, and you will see that its behaviour is still more curious than that of the graphite with which I operated a minute ago. I take even a smaller quantity of this graphic acid than we did of the graphite. I apply heat to the flask containing the substance; you see, from the sparks, the combustion that is taking place inside the flask, and you also see the large amount of soot that is being generated. [A pause]—The action is now over, and you will observe that our flask is completely full of soot. In this way, I have converted our graphite back into ordinary charcoal, of which I have here sufficient to fill the tube entirely.

I have told you one or two ways in which graphite may be made, and now I will show you another. You are all familiar with the diamond. Mr. Tennant has lent me a collection of diamonds which are in the tray before you. I am afraid they will not prove as interesting to the ladies as if they were mounted in a different fashion, but they are mounted in this way to display their various colours (*). Of course, the finest diamonds are colourless. You see the beautiful manner in which these stones glisten now I illuminate them by the magnesium light; and if you take the trouble to examine them after the lecture, you will see that they are well worthy of examination, because they are not cut simply in the ordinary form, but so as to show that they present nearly all the colours which diamonds possess. Now, the diamond has this property—that it will stand a red heat. You may make it red-hot, and it will be none the worse for it; but there is a degree of heat which it will not stand. The degree of heat, capable of being produced by the electric arc, alters the diamond; and into what does it alter it? Into a mass of graphite or plumbago. We come, then, to this conclusion,—that as diamond is the same thing as plumbago, and as plumbago in its composition is nothing more than ordinary

charcoal, therefore diamond itself is only charcoal; and we can ascertain this fact in another way, for when a diamond is burnt in oxygen it yields this carbonic gas. I now want to show you the result of its combustion. Here we have a jar of oxygen gas, here we have a diamond, and here is an arrangement for making the diamond red-hot by means of a galvanic current. I introduce the diamond into our globe of oxygen, and while there I will make it red-hot. When it has once become so, it will burn in the globe for a minute or two. I am now making our diamond red-hot; it takes some little time to bring it to the proper heat: but as soon as this is attained, it will begin to burn. The burning of the diamond in oxygen is attended by the formation of carbonic gas, the presence of which is indicated by the ordinary lime-water test.

There is one further remark I wish to make to you relative to the diamond. It differs from plumbago in appearance, and also in specific gravity, for it is a very heavy substance. An ordinary piece of plumbago is about two and a quarter times as heavy as water. Charcoal is from one and a half to twice the weight of water, but the diamond is three and a half times as heavy, and hence is a very much heavier

substance than ordinary charcoal, or even than plumbago. And so, again, with regard to electricity; there are some bodies through which the electric current will pass freely; through others it does *not* pass, as they are capable of resisting the current. Now, a diamond resists the current, whereas charcoal does not; thus a diamond differs from charcoal in this as well as in many other very important particulars.

I will now call your attention to a remaining property of carbonic gas, which is that, when it is compressed, it is capable of being actually brought into the liquid state ([27]). That iron vessel before you is at present filled with what was carbonic gas, but is so no longer; it is liquefied, and might be called *carbonic liquid*. It is like water in appearance, and consists of nothing but carbonic gas compressed into a liquid condition. This liquid is a very curious substance, and when, by removing the pressure, we allow it to escape into the gaseous state, it becomes intensely cold. Why it thus becomes cold I cannot stay to tell you, but when this reduction of temperature takes place, the substance is partly converted into the solid state ([28]). When converted into the gaseous state, or into carbonic gas, the liquid becomes so cold, and absorbs so

much heat, that the remainder is converted, as I have said, into the solid state. I am now going to collect some of this solid substance in a box. I warn you that upon opening the cylinder there will be a little noise, but you must not be startled by it. Before putting the box upon the cylinder, I will allow some of the carbonic gas to escape, and you will see it solidifying in the air. [Some of the compressed gas was then allowed to rush out of the cylinder, and on doing so it formed a white snow-like shower of solid carbonic acid]. You see I thus get a large quantity of this carbonic snow.

I will now try to collect some of this solid matter in a box. [Some of the compressed gas was allowed to escape into a brass box, and there became solidified]. Our box is now full of the solidified gas, which I will empty out. That you may see how cold it is, I will place a piece of ordinary wet flannel round the box. You see that when I do so, the flannel is at once frozen so firmly to the box, that I can support its weight by means of the strip of frozen flannel. I will now take a portion of this solid gas and put it into a retort, and then you will see its gradual conversion into the gaseous state, and I shall be able to collect some of the gas over water. After putting the substance

into the retort, I close it with a stopper, and that which was carbonic solid is gradually, as you see, converted into carbonic gas, and that gas is being collected over water. I will now give you another illustration of the property of this substance. Although it is so very cold, yet when I place a piece of it upon my hand, I do not feel it to be so; I can keep it there for a considerable time. The solid itself does not touch my hand, for it is separated by some of the carbonic gas into which it is becoming resolved, and hence it does not seem very cold to me, although it very readily froze the piece of flannel. If I let some of this substance come into contact with water, you will see its curious action; I will allow a piece to float on water, and you see it is gradually and very slowly evaporating. It does not freeze the water, although it froze the flannel in an instant. Here is another illustration of this property. If I take a common soda-water bottle, and fill it with ordinary water, I convert this ordinary water into soda-water, by adding to it some of this solidified carbonic gas. I will take a few pieces and drop them into a bottle of water. I then cork the bottle and shake it up for a minute or two, and we shall find that the carbonic gas so produced dissolves in the water, and converts what was a bottle of

ordinary water into a bottle of soda-water. [After a short interval]—The solid carbonic gas which I put into the bottle of water has slowly dissolved, and I know that the experiment has succeeded, because it is as much as I can do to hold the cork in the bottle. You see, when I remove my hand, that the cork flies out, and that we have obtained a bottle of soda-water which effervesces in the usual manner.

I will give you another illustration of the freezing properties of this solid carbonic gas. I here take a stool, and upon it I pour a little water. I then place upon the wet stool a glass beaker, into which I put some of the solidified gas. The evaporation from the substance contained in the glass is so rapid, that in an instant or two I shall succeed, I have no doubt, in freezing the beaker to the wet stool. [The freezing took place almost instantaneously, and, in order to demonstrate the firmness of the adhesion, the lecturer lifted the stool by means of the glass beaker which was frozen to it]. You see the vessel is frozen to the stool with very considerable force, and a good deal of strength would be required to detach it.

I will now endeavour to freeze a quantity of mercury, with a further portion of this solidified matter. [Some mercury was frozen by being

brought into contact with the solid carbonic gas.] I have now frozen our mercury sufficiently for you to see the character of this freezing action. I hold the mercury by a wire, and, in this way, I can lift it. I will suspend the mass of mercury in water, where it will melt, and when it melts, you will see it pouring down through tubes of ice. Now when you consider that the temperature required to freeze mercury is exceedingly low—forty degrees below the freezing point of water—you will be able to form an idea of the great degree of cold which we can attain by the use of this solidified gas ([29]).

We have sufficient material left for a final experiment. I will put some of the solidified gas into a red-hot crucible, add a little ether, and then some mercury, and even then the mercury will be frozen. [The experiment was performed with a successful result.] We have succeeded in actually freezing mercury in a red-hot vessel. Here we have brought the mercury to a solid mass. I will now put it into some water, and it at once begins to liquefy, and as it liquefies it freezes the water, and forms little hollow tubes of ice, through which it falls to the bottom.

LECTURE V.

DISULPHIDE OF CARBON—CARBON—CARBONOUS OXIDE—CARBONIC GAS.

YOU will remember that when a diamond is made exceedingly hot, it is converted into a mass of graphite, or plumbago, or black-lead, these three terms meaning the same thing. Now as black-lead, or plumbago, or graphite, is nothing more than charcoal, and as diamond can be converted into black-lead, it follows that diamond is in reality charcoal. But we know this in another way; when we burn a diamond, we find that the only substance it yields is burnt or oxidised carbon—in other words, carbonic gas. I will now show you once more the combustion of the diamond. In this globe of oxygen gas is a diamond, surrounded by a piece of platinum wire; this wire I will make red-hot, and it will communicate its red heat to the diamond. As soon as the diamond is thus

made red-hot, it will burn in the oxygen gas. [The experiment was performed as described.] The diamond has now begun to burn. You see its brilliant glow in the globe of oxygen, as it is being slowly consumed. I take away the platinum wire, but the diamond continues hot quite independent of it, and gives a bright spot of light, which is due to its strong ignition and to the fact that it is actually burning. The diamond is being converted into burnt or oxidised diamond, or into burnt or oxidised charcoal ; and we may test this in an instant by introducing a little lime-water, which we thus convert into a mixture of chalk and water, chalk being the compound formed by the combination of burnt carbon, or burnt diamond, with lime. I shake up a little lime-water in the globe, and though, for obvious reasons, I have not burned a very large diamond, yet I have obtained this carbonic gas, or oxide of carbon, or burnt carbon, by means of which I have converted our lime-water into a mixture of chalk and water. This effect is, I think, visible all over the theatre.

We have now considered a great many of the changes of carbon or charcoal. We have considered the change of charcoal into black-lead, the change of diamond into black-lead, and the

change from black-lead back again into charcoal; also the change of charcoal, of black-lead, and of diamond, into burnt charcoal or carbonic gas. We have likewise considered indirectly the conversion of certain compounds of carbon and hydrogen into carbon, in the imperfect combustion of coals, candles, and similar substances.

I want now to call your attention to some other changes which charcoal is capable of manifesting, amongst which is the change it undergoes in its combination with this substance —sulphur or brimstone.

We usually see sulphur as a solid substance—in the form of sticks or rolls; it is somewhat brittle, but is very easily brought into a liquid state. If we heat it, it melts like a piece of ice, and yields liquid sulphur, just as the melting of a piece of ice yields water. If we heat the sulphur still further, it will boil just like water, and in that way we obtain sulphur gas, which is a vapour of a deep orange colour. Here is some sulphur which is at present liquefied; in a minute or two it will boil, and then the flask containing it will be full of the vapour of sulphur, which you will recognise by its deep orange colour. Just now the vapour is scarcely visible, for the sulphur does not yet fairly boil;—it is now

beginning to do so, and soon you will see the flask filled with a deep orange-coloured and perfectly transparent gas or vapour. This gas or vapour is characterised by its considerable weight, by its dark orange colour, and by the facility with which it is changed back into the liquid state; wherein it differs from oxygen gas, although in some respects it corresponds very closely with it. You will remember that not only do ordinary combustible substances, such as coals or candles, burn in oxygen gas, but certain metals also. I showed you the combustion in oxygen of zinc and of iron; I will now show you the burning of some metals in this vapour of sulphur, and you will see that they burn in it very much the same as in oxygen. I take a piece of copper, and first warm it a little; I then introduce it into the sulphur vapour, and you see that it burns very completely, just as our piece of iron did in oxygen. You observe that when I introduce the piece of copper into the sulphur vapour, the copper becomes brillantly hot, and gradually consumes in the interior of the flask which is filled with this deep-coloured vapour. In this particular, sulphur vapour corresponds very closely with oxygen. Now, will a piece of charcoal burn in this deep orange-coloured sulphur-gas or

vapour, which is now quite visible? I light a piece of charcoal: if I put it into a globe of oxygen it would burst into a flame; but when I put it into sulphur vapour, it is immediately extinguished—it will not burn in sulphur. Nevertheless, it can be made to enter into combination with it; that is to say, if, instead of trusting for the necessary amount of heat to the burning of the charcoal in the sulphur vapour, we heat the charcoal strongly, and keep it strongly heated whilst in the sulphur, then the carbon and the sulphur will enter into combination one with another. When iron and oxygen burn, we get oxide of iron; sulphur and copper burnt together yield disulphide of copper, just as by combining copper with oxygen we obtain oxide of copper. Now, if we introduce the heated charcoal into sulphur vapour, and burn it there by keeping it hot, we get disulphide of carbon.

What is the nature of this disulphide of carbon? In the first place, it is ordinarily a liquid. Here we have some specimens of it. You will remember that the carbonic gas can be liquefied, and I showed it to you in that state; in the same manner we can gasify disulphide of carbon. This tube, which looks as if it were empty, contains some of the

gas of disulphide of carbon. This gas is very easily reduced into a liquid state; if I allow the ordinary weight of the atmosphere to press upon it, the mercury will rush up the tube, and some of the vapour will be converted into liquid. By putting on a little pressure from my mouth, I can convert the whole of this gas into liquid. [The pressure of the atmosphere was allowed to operate on the contents of the tube.] You see the mercury already begins to rise, showing that we have converted a considerable quantity of our disulphide of carbon gas into disulphide of carbon liquid. By blowing into the tube with a little force, I shall be able to push the mercury up to the top of it, and by that additional pressure the whole of the disulphide of carbon gas will be converted into a liquid, just as by means of a force pump I was able, at the last lecture, to pump a great quantity of carbonic gas into the interior of the vessel, and so obtain it in a liquid condition. You will notice that when, through my blowing, the mercury reaches the top of the tube, it will strike it with a slight noise, which many of you will be able to hear. This disulphide of carbon, then, we may regard as a substance which is sometimes in the liquid state, with a strong tendency to become a gas or vapour, and some-

times in the gaseous state, with a strong tendency to become a liquid.

Now for some of the properties of this compound when in the liquid state. I ought to warn you that disulphide of carbon, whether a liquid or a gas, is characterised by a somewhat disagreeable odour. Perhaps on this account I ought not to bring it before you, but it has properties so remarkable in many respects that I cannot refrain from introducing it. First with regard to its weight. It is very much heavier than water; to show you how heavy it is I will pour some of it into this water. In these experiments I usually colour the water blue or red, to render it visible to you, but in this instance I have coloured it brown, by using iodine, for reasons which you will presently understand. I pour some of this disulphide of carbon through the brown water, and you see it at once falls to the bottom; and something else also happens. The liquid poured into the brown water was colourless, but now that it has fallen to the bottom through this brown liquid it has become decidedly pink in colour; but there is something more. I shake the two liquids up together, and you will find, I think, that the disulphide of carbon will take away all the brown colour, and instead of itself becoming brown, it will become pink. It

is a very curious circumstance with regard to this iodine, that it dissolves in some liquids, forming a brown liquid, but that on dissolving in disulphide of carbon it forms a deep pink. The disulphide of carbon has fallen to the bottom and assumed its beautiful crimson colour, and I think we shall find that by the time it has quite settled we shall have two distinct layers of liquid, and the upper one will be colourless. You will observe how colourless the supernatant water will eventually become. Disulphide of carbon is heavier than water, in the proportion of about thirteen hundred to a thousand; that is to say, if we were to take a volume of water which weighed a thousand grains or a thousand pounds, and the same volume of this disulphide of carbon, we should find the disulphide of carbon weighed thirteen hundred grains or pounds. But, although this substance is heavier than water, it is not so heavy as a saturated solution of salt. [This fact was illustrated by a small quantity of a saturated solution of salt being placed at the bottom of a vessel of disulphide of carbon, and there remaining.]

Now for another property of this disulphide of carbon. It consists of sulphur or brimstone, and charcoal, and both brimstone and charcoal are very combustible or easily burning bodies;

and the fact that the brimstone and the charcoal are in combination instead of being separate, does not at all interfere with their combustibility. Accordingly, if I moisten a sponge with a little disulphide of carbon, and bring it to the flame, you see that it at once burns with a lambent blue flame. There are two or three very interesting points connected with the combustion of this substance. When it burns, and there is sufficient air, the charcoal is converted into oxidised or burnt charcoal, in the form of carbonic gas, and the sulphur into oxidised sulphur or sulphurous gas. But if there is not sufficient air what will happen? The charcoal only will be burnt. You will remember that when we took an ordinary candle, or a gas flame, and cut off the supply of air, the hydrogen only was burnt and not the charcoal. In the present case when the supply of air is insufficient for perfect combustion, the charcoal burns and the sulphur does not. That is one interesting point connected with the burning of disulphide of carbon. The other is, that it is one of those substances which are ignited with the greatest ease. I have here an ordinary test tube, containing a little olive oil. I heat this up to a temperature a long way short of red heat—a temperature which corresponds to about four

hundred degrees Fahrenheit, or about twice as high as that of boiling water. The tube of oil being sufficiently hot, I will place it in the disulphide of carbon vapour, and I want to show you that with that tube of hot olive oil I shall be able to set fire to the disulphide of carbon. I will pour a little of the substance into these glasses, and then try to ignite it, not by a match or a lighted taper, but simply by this tube of heated oil. [Disulphide of carbon vapour was inflamed by the tube of hot oil.] You see that we can readily set fire to this substance by means of a little heated oil. It is, in fact, one of the most easily combustible of all the common substances known to chemists. It gives off vapour, or becomes vapourised, very easily and very quickly, and, moreover, the gas or vapour of the disulphide of carbon is very heavy. It is much heavier than carbonic gas which I showed you in a previous lecture, for whereas carbonic gas is only about one and a half times as heavy as air, this is two and a half times as heavy. I will give you an illustration of these two points together—the great facility with which this substance is converted into vapour and the heaviness of its vapour; and then, thirdly, I will illustrate to you its inflammability. I have here a piece of sponge moistened with the disulphide;

I put it at one end into the corner of this long flat box, and under these circumstances it will give off vapour. I want to see at what distance I can light the vapour which is given off from the moistened sponge. The vapour will doubtless fill the box, and I shall be able to ignite it from the extreme end or corner of the box. I approach the flame carefully with the light, and when the vapour is lighted, it shrinks at once to the other end. You see that it is very easy to ignite, and difficult to extinguish. I will now give you some further illustrations of the heaviness of this disulphide of carbon. Here I have a bottle apparently empty, but really containing disulphide of carbon gas. I will pour a little of this heavy gas into this tall jar, just as the other day I poured the carbonic gas. I take our apparently empty bottle, and having poured the gas from it into the jar I apply a light and ignite the gas. Now we will see whether we cannot go a little further. We have now two glasses; I take the bottle containing the disulphide of carbon vapour, and fill this first glass with it. I now pour some of the gas from the first into the second glass, into which I put a light, and you see the gas takes fire. I will repeat the experiment, using three smaller glasses instead of the two

larger ones. I take the bottle of gas, and begin by filling this first glass; I transfer a portion of the contents of the first glass into the second, and next I pour a portion of the gas from the second glass into the third. Now we will see whether all these three glasses contain this inflammable gas. [A lighted taper was applied successively to the third, second, and first glasses, and in each instance the presence of the disulphide vapour was manifested by its ignition on contact with the flame.] We might go on in this way; indeed, I have extended the experiment to as many as four or five glasses. Now I have here a glass barrel, which is apparently empty, but really containing this disulphide of carbon vapour, and so heavy is the vapour, that I shall be able to draw it out from the tap of the vessel. I hold a beaker under the tap, and so draw into it a little of the vapour. The beaker being sufficiently full for our purpose, I turn off the tap, and on bringing a light near the beaker, the gas contained in it takes fire. I will give you one more illustration of the weight of this disulphide of carbon. You know it is a very common practice to draw off liquids by means of a syphon, and I will try whether this can be done in the case of this vapour. I insert one end of the syphon in the vessel of vapour, and fill the

syphon in the ordinary way by sucking it. Our syphon is now full, and the gas issues from the end of it. I hold these vessels under the syphon in order to receive the gas which is flowing from the end of it, and you see that I can thus catch the gas, and then I shall be able to set it on fire.

I have given you several illustrations of the facility with which this substance is converted into vapour, and also of the inflammability of the vapour. I want now to show you that if I vapourise it more rapidly, which may be done in a current of air, I can produce a great amount of cold. In my last lecture I showed you the amount of cold that could be produced by the vapourisation of the liquefied carbonic gas. Now I want to show you the amount of cold that can be produced by the vapourisation or gasification of liquid carbonic disulphide. I pour some water on the top of this stool, and then place the beaker on the wet part. I next pour some disulphide of carbon into the beaker, and blow a current of air upon it. By this means, our disulphide of carbon is very quickly converted into vapour. It is now rapidly vapourising, at the same time producing a very intense cold, and I have no doubt that in a minute or two this beaker will have become so firmly frozen to the stool that

I shall be able to hold it up by means of the beaker, just as I did the other day when illustrating the cold produced by the spontaneous vapourisation or gasification of the solidified carbonic gas. You will remember that in that case I allowed the vapourisation to take place spontaneously. In the present instance I cause the vapourisation by a current of air, which is being blown upon the liquid from below. [After a short interval the glass beaker was found to be frozen to the top of the stool.] It is now frozen, but I will allow it to remain a little longer so as to make sure that it is frozen sufficiently firmly to allow me to hold up the stool by the glass. [After a short pause]—Here you see I am lifting up the stool by the beaker; the two adhere so closely that it requires some considerable force to separate them.

In the experiment just performed I vapourised some disulphide of carbon simply by blowing air upon it; but now I am going to boil it, and I want to show you what a beautiful and extensive flame may in this way be produced. It is a liquid which both boils and vapourises very quickly. It is beginning to boil, and you see the beautiful lambent flame with which it burns. I now turn on a supply of oxygen, and in this I burn the disulphide vapour. I want you

for an instant to form an idea of the length of this brilliant and peculiar blue flame; but I must not let it burn long, because it produces a great deal of sulphurous gas, which is very unpleasant.

The last property of disulphide of carbon to which I wish to call your attention, is the mode in which it burns, not in oxygen or in air, but in another gas which I have not hitherto considered in my lectures on carbon, namely, an oxide of nitrogen [80]; and I will show you the very brilliant manner in which the disulphide of carbon will burn in it. Here we have a cylinder of the gas, and here, in this small glass globe, is our disulphide of carbon. I let the disulphide of carbon globe fall to the bottom of the jar; of course, in doing so it breaks, as you see, and I shake it up with the other gas. [The mixture was then ignited, and produced a very brilliant flash.] This is the last experiment that I have to show you with this liquid or vapour, which, although very interesting, is disagreeable in many respects.

And now we pass on to the consideration of an entirely different section of our subject. You will remember that ordinary charcoal is obtained from wood. When wood is strongly heated or burnt in a limited supply of air, the carbon of

the wood scarcely burns at all, and we have this carbon preserved to us in the form of charcoal. Charcoal, then, is the chief constituent of wood, in which substance it exists in the unburnt condition; and not only does charcoal exist in wood, but in nearly all vegetable substances. The seeds of wheat contain starch, in which charcoal exists; sugar, too, contains a considerable proportion of charcoal, and when these substances are burnt they leave a great deal of charcoal behind. Here, for instance, we have some wood shavings. Now I can very readily show you the charcoal in these wood shavings, by pouring upon them a little of that corrosive substance called oil of vitriol ([a]). By letting this liquid act upon the shavings for a little time, they quickly change into a mass of black charcoal. In the case of such a substance as sugar, the action takes place still more rapidly. Here in this large cylinder are some pieces of sugar; I moisten them with a little hot water, and then pour some oil of vitriol upon them, and you observe that when I do so the sugar is at once converted into a mass of black charcoal. [The sugar became rapidly charred by the sulphuric acid, and the admixture emitted steam, and swelled into a black spongy mass, overflowing the glass jar in which the experiment was

performed, and which, in the first instance, was not more than one-third full.]

All these substances which I have mentioned to you as containing carbon, burn very readily into burnt carbon or carbonic gas. If, for instance, I burn a piece of wood in a small tube of oxygen, you will find that a brilliant flame is produced, and the result will be the formation of carbonic gas, which is proved by the application of the lime-water test.

Instead of burning the charcoal directly in oxygen gas, as I have done in two or three previous experiments, I am now going to burn it in a substance which contains this gas; and it shall be burnt under water, and the carbonic gas which is produced collected in a cylinder. [A mixture of nitre and carbonaceous matter was burnt in a tube under water.] You see that, in this way, our cylinder, which was full of water, is now becoming full of burnt charcoal or carbonic gas. I cause some of the gas to bubble up through lime-water, and you see the lime-water becomes converted into a mixture of chalk and water, proving that we really have produced gas of this kind. I will now collect some of the gas in a separate vessel, and again show you its nature by its property of extinguishing flame.

Now, if you reflect a little, I think you will

come to this conclusion,—that substances which grow, vegetable substances, are all of them destined ultimately to become burnt, or to undergo a change equivalent to burning. A great deal of wood, for instance, is chopped up and used for fire wood; a great deal more is used for building ships, for forming the interior portions of houses, and making furniture. These ships and houses and furniture last for a certain time; they gradually pass from an honourable into a dishonourable condition; old furniture is put into the lumber room; the disabled ships are broken up and destroyed, and at last they go to the fire, where the carbon becomes oxidised or converted into carbonic gas. But there is a great deal of vegetable matter which never undergoes this burning. In the autumn a large quantity of leaves fall to the earth and there undergo some sort of change; this change is, in fact, a very slow burning, but without the phenomena of ignition which we see in the case of a fire, although the leaves are converted into carbonic gas or oxidised carbon. Now here is a bottle which contains some decaying wood, and, as I showed you in the last lecture, a lighted taper introduced into the bottle is at once extinguished by the burnt carbon or carbonic gas, which has been produced by the oxidation of

the wood in the process of decay. Here, again, is some rotting sawdust; this also gives rise to carbonic gas, which extinguishes a lighted taper introduced into it. You see, therefore, that although the wood does not actually undergo the process of burning, as we are accustomed to see it, it does undergo the process of decay, which is a conversion of the original carbon into burnt charcoal. But a great quantity of vegetable substance neither undergoes burning nor decay, but is eaten. We know that cattle feed largely on corn and straw, and we ourselves consume much wheat and other grain. In these instances, although the vegetable substances do not, strictly speaking, *decay*, yet they undergo another form of the process of oxidation, by which burnt charcoal is produced. For example, if I take a little lime-water, and blow, or rather breathe, through it, we have evidence of a considerable amount of burnt carbon being present in the breath. In this case, the carbon, instead of having been burnt in a furnace, has simply been burnt in our bodies, thereby rendering them warm, just as when it is burnt in the fire it warms a room. In order to show you the presence of carbonic gas in the breath, it will be quite sufficient for me to breathe into a bottle of lime-water. Here is one—I breathe

into it. Close it, and shake it up, and by so doing I have, as you see, produced a very considerable quantity of chalk, showing the presence of carbonic gas, or burnt carbon.

All vegetable tissue, then, comes sooner or later to be burnt, or oxidised, or converted into carbonic gas.

The next point which I should like you to notice is the unburning of carbonic gas. How is it possible to do this? On this subject I must just call your attention to what is here written upon the diagram:—

Carbon } Carbonic gas.
2 Oxygen }

Carbon } Carbonous oxide.
1 Oxygen }

Carbonic gas is really a combination of one proportion of carbon and two of oxygen. Now there is another oxide of carbon of which I have not yet spoken, which consists of one proportion of carbon and one of oxygen; it is called carbonous oxide (*). If I take carbonic gas and half unburn it, I remove one-half of the oxygen, and the result is carbonous oxide. How is this done? Well, one way is by burning something in carbonic gas. If we take one of the few substances that will burn or oxidise in carbonic gas, we shall find

that that substance, by its burning, will take away some of the oxygen from the carbonic gas, and thereby convert it into carbonous oxide. One of the commonest forms of this experiment is to take some carbonic gas and pass it through a tube filled with red-hot iron. Under these circumstances, the iron takes away some of the oxygen, or unburns the carbonic gas down to carbonous oxide; but I am about to show you a more convenient form of the experiment, for which I am indebted to Dr. Taylor.

I take, not metallic iron, but metallic magnesium, and I will show you that, although a taper is extinguished in the carbonic gas, yet the magnesium will burn. I introduce a piece of ignited magnesium, and it continues to burn in the carbonic gas. You see that a taper, when introduced into the same gas, is extinguished, whilst the light of the magnesium, under the same circumstances, is so brilliant that it almost blinds one for the moment. Now when this metal —magnesium—burns in this way, it reduces, or decomposes, or unburns the carbonic gas to the state of carbonous oxide. But there are some metals, you will remember, which go beyond that; when a piece of sodium is burnt in carbonic gas, it not only unburns the carbonic gas to the state of carbonous oxide, but

it takes away all the oxygen, and again reduces the carbonic gas to a piece of charcoal. By means of the magnesium, we unburn the gas by taking away one proportion of oxygen, and reducing it to a compound which contains one proportion of oxygen and one of carbon; but when sodium is used, the two proportions of oxygen are taken away and the carbon is left free.

Here is a vessel generating carbonic gas in the usual way. The gas is being conducted into this glass globe, and it is there made extremely hot by the action of the electric spark. An intense degree of heat is produced, and, under these circumstances, the carbonic gas breaks up into a mixture of carbonous oxide and oxygen. Now, for this purpose we do not necessarily require the heat of the electric spark. Even the heat that we can obtain by the combustion of a flame of ordinary gas in a current of oxygen, is quite sufficient for our purpose. I have here a supply of coal gas; I pass oxygen into its flame, and with this flame I will heat a platinum coil, through which I now allow the carbonic gas to pass, and, in its passage, it is decomposed into carbonous oxide and oxygen. To give you some idea of the amount of heat which can be produced in this

way, I will hold a plate of iron in front of the blow-pipe flame. You see that although this plate is one of considerable thickness, it is utterly unable to withstand the high degree of heat which I am in this way applying to it. [Holes were burned in the plate of iron at those points on which the flame was allowed to impinge.]

When carbonic gas is subjected to this extreme degree of heat, it undergoes decomposition —not into carbon and oxygen, but simply into carbonous oxide and oxygen. It only becomes one-half unburnt. Now are there any agencies in nature by which this carbonic gas can be completely unburnt? There is one, and one only, that is, through the influence of vegetation, under exposure to the sun's rays. If, in the spring time, when the sun is shining, we take some rapidly growing plant—a sprig of mint for instance, which answers the purpose very well—and immerse it in a vessel of water charged with carbonic gas, that carbonic gas will undergo an unburning; its oxygen will gradually bubble up from the leaves of the plant, and rise to the top of the vessel of water. But what will become of the carbon? It will be converted into starch and wood and sugar and other substances, which go to form the living plant. By this means only can the

carbonic gas be unburnt into carbon, which enters into the tissues of the plants, and into oxygen, which is given off again into the atmosphere.

Now what is the point of interest in an unburning of this kind? If I were to allow an electric spark to pass through the air, it would give out a certain amount of heat, but, on passing through the carbonic gas, it emits a considerably less amount. Well, what has become of the difference? It has gone somewhere. If I take this mixture of carbonous oxide and oxygen, produced from the carbonic gas by the passage of the electric spark, and set fire to it, it gives out exactly the amount of heat that disappeared from the heat of the spark. In that case, the carbonous oxide and the oxygen burn together. I will give you an illustration of the combustion of these two substances. Here is a large cylinder of the half-unburned carbonic acid; I set fire to it, and you see the curious blue flame which it emits, and the peculiar manner in which it burns. I have also some of the carbonous oxide burning from a tube, and if I hold over its flame an empty bottle, I shall be able to collect the burnt carbonic gas which is so produced. (You see the beautiful blue flame which the carbonous oxide sends out from the tube.) I may also show you the considerable

amount of heat which it gives out in burning. If I introduce into the flame a piece of platinum wire, you see it immediately becomes very red, proving the flame to be exceedingly hot. Now when I burn together the carbonous oxide and the oxygen, which have been separated from one another, exactly the same amount of heat is given out by it that was absorbed from the electric spark by the products of the unburning of the carbonic gas, and was not used in heating the surrounding air.

Now, if the sun, instead of shining on the plants which grow on the earth's surface, were to shine entirely upon the stones, it would heat the atmosphere a great deal more than it does. As it is, a portion of the sun's heat disappears. What, then, becomes of it? It is absorbed by the vegetation. The amount of heat absorbed by a growing piece of wood, in unburning the carbonic gas of the atmosphere into charcoal and oxygen, is exactly the amount which the piece of wood is capable of giving out when its carbon is re-burned in the air; and, accordingly, when we burn coals, or wood, or peat upon our fires, or consume bread, and oil, and wine in our bodies, and thereby produce a considerable amount of heat either in the fires or in our bodies, we are really manifesting once more, in

the form of heat, the sun's rays, which years and years before shone upon the plants from which those substances were derived. When we burn any one of these substances we recover from them the sun's heat which disappeared in their growth. We will here burn some sugar, and we shall easily be able to regain an exhibition of the sun's rays that were absorbed in separating the carbon of the sugar from the oxygen with which it was in combination, and which, upon being separated, was discharged into the air. I pour a drop of this liquid upon the mixture of sugar ([88]), and you see the very brilliant evolution of the sun's rays which were stored up in the formation of the sugar.

And now it only devolves upon me to thank you heartily for your kind attention during these lectures. I hope, that whenever again you see a piece of coke, or a piece of charcoal, or a piece of marble, or a growing plant, you will remember the curious relations of change which exist between them, and how the one is capable of being converted into the other.

NOTES.

LECTURE I.

(1) PAGE 4.—Salt cake is anhydrous sulphate of soda; it dissolves in a little more than seven parts of water at the ordinary temperature, and during the act of solution the liquid becomes warm.

(2) PAGE 6.—The substance used was magenta or acetate of rosaniline.

(3) PAGE 16.—The term basic is applied to salts when they contain more metallic base than is sufficient to form a normal salt. Goulard solution (a term used in pharmacy) is a mixture of several basic acetates of lead, chiefly the tribasic; it is an alkaline liquid, readily decomposed by carbonic acid with precipitation of carbonate of lead.

(4) PAGE 20.—Quick-lime, or caustic lime, is an oxide of the metal calcium; it is obtained on the large scale by the same process as here adopted, namely, by igniting carbonate of lime. When water is poured over quick-lime, it is absorbed with great avidity, and in the course of a minute the lime becomes hot, gives off a great deal of steam, and crumbles to a dry white powder, which consists of a combination of lime and water, called hydrate of lime. Hydrate of lime dissolves in about 600 times its weight of water at the ordinary temperature, forming an alkaline solution.

(5) PAGE 21.—Several test-papers are used in chemistry; they are made by wetting sheets of unsized paper with different solutions, and drying them in pure air; they

are then cut into small pieces, and kept in closed bottles. The following are the test-papers used by the lecturer in these experiments:—

Brazil-wood paper, prepared from the decoction of Brazil wood; it is turned purple by alkaline solutions.

Dahlia paper, prepared from an infusion of the petals of the *Georgina purpurea*; it is turned green by alkalies and red by acids.

Turmeric paper, prepared from decoction of turmeric; it is turned brown by alkalies.

Red litmus paper, prepared from an acid infusion of litmus; it is turned blue by alkalies. Blue litmus paper, prepared from ordinary infusion of litmus, is turned red by acids.

(6) PAGE 22.—Lime-water, when added to solutions of metallic oxides, precipitates those which are insoluble in water. The blue precipitate was oxide of copper, from a solution of the sulphate. The black precipitate was protoxide of mercury, from a solution of the protonitrate. The brown precipitate was sesquioxide of iron, from the sesquichloride. The green precipitate was sesquioxide of chromium. The orange precipitate was hydrated oxide of uranium, containing lime, precipitated from nitrate of uranium. The white precipitate was oxide of zinc, precipitated from sulphate of zinc.

(7) PAGE 27.—The light given off by burning sodium is monochromatic, that is to say, it is of one colour only—a pure yellow. On the other hand, burning magnesium gives out light of all colours, and therefore appears white. When a diagram painted with brilliant colours is illuminated by magnesium light, all the colours are seen in their natural appearance, as in daylight; but when illuminated with sodium light, only those portions of the diagram are seen which will reflect yellow light, whilst the other parts appear black. The inability of sodium light to show any colour but yellow causes the human countenance to assume a horrible death-like appearance when seen by this light, as the red and pink of the complexion appear different shades of black and yellow.

LECTURE II.

(8) PAGE 40.—According to Struve, 100 cubic inches of Seltzer water contain 126 cubic inches of carbonic gas.

(9) PAGE 41.—The amount of carbonic gas present in the air of the open country has been found by different observers to vary between 3 and 10 volumes in 10,000 of air. Above the ocean, it varies between 5·4 parts in 10,000 during the day, and 3·3 parts during the night.

(10) PAGE 45.—According to Regnault, a cubic foot of air, at the usual temperature and pressure, weighs 532·725 grains. Faraday calculated that the air in the theatre of the Royal Institution, where these lectures were delivered, weighed above a ton.

(11) PAGE 49.—The green coloured air was chlorine gas; the brown was the vapour of bromine.

(12) PAGE 52.—The specific gravities of the four liquids used in this experiment are

Mercury..	13·59
Chloroform	1·49
Water	1·00
Ether	0·72

LECTURE III.

(13) PAGE 64.—When mercury is reduced to a very low temperature ($-40°$) it solidifies to a tin-white ductile mass, capable of being cut with a knife and pressed into moulds. Mining operations are carried on in some parts of Norway where the temperature in winter is sometimes below the freezing point of mercury. A solid bullet of mercury may there be cast and fired from a rifle, if the precaution is previously taken to cool the bullet mould and rifle down to the necessary low temperature by exposing them for some hours to the open air.

(14) PAGE 64.—When mercury is kept for a consider able time freely exposed to the air, at a temperature approaching its boiling point (360° C.), it gradually absorbs the oxygen, and becomes converted into mercuric oxide, which is a brick-red crystalline powder. When this mercuric oxide is heated to redness, it gives off the oxygen which had been absorbed at a lower temperature, splitting up into metallic mercury and oxygen gas.

(15) PAGE 67.—The atmosphere shows very minute differences of composition when examined at different localities; thus a million parts of air from the following

[illegible] were found to contain the following proportions of oxygen:—

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

(16) Page [illegible].—The light emitted by burning sodium is monochromatic, consisting of pure yellow light; whilst that from burning magnesium contains rays of all colours. The phenomenon has already been explained in note 7.

(17) Page [illegible].—Two volumes of hydrogen, on burning, unite with one volume of oxygen, and form two volumes of water-gas, or steam, which condense on the cold sides of the glass vessel into drops of water.

LECTURE V.

(18) Page [illegible].—The metallic solution was acetate of lead; paper impregnated with this is a very delicate test for sulphuretted hydrogen, turning black in the presence of this gas, owing to the formation of sulphide of lead.

(19) Page 93.—A solution of nitroprusside of sodium is turned purple on the addition of sulphuretted hydrogen; and a solution of tartrate of antimony gives an orange precipitate under the same circumstances.

(20) Page 96.—It is possible to cause charcoal actually to burn with visible ignition when immersed in liquid nitric acid. A stick of charcoal will take fire if it is warmed and then dipped into a mixture of two parts of the strongest nitric acid and one part of fuming sulphuric acid.

(21) Page 100.—The *volume* of carbonic gas which water will dissolve, is nearly the same at all pressures; the *quantity* of gas dissolved therefore increases with the pressure. *Cold* water dissolves carbonic gas more readily than hot water. At the freezing point, 100 cubic inches of water dissolve 176·97 cubic inches; at the ordinary temperature of the atmosphere, about 100 cubic inches, or an equal bulk; whilst at the boiling point, carbonic gas is insoluble in water.

(22) Page 105.—Boiler deposit, or *fur*, does not always consist of carbonate of lime. If the water contains

sulphate of lime, this is also deposited together with the carbonate of lime.

(23) PAGE 107.—Considering the density of atmospheric air to be 1·000, that of oxygen is 1·105, and that of carbonic gas 1·524.

(24) PAGE 109.—Carbonic gas may be coloured brown by peroxide of nitrogen. This gas is obtained easily by heating the lead nitrate in a test tube; and by means of a bent tube the brown fumes are conducted into the vessel containing the carbonic gas. Bromine vapour may be used, but the smell is very disagreeable. A simple method of rendering carbonic gas visible is that described by Priestley—"Experiments and Observations on Different Kinds of Air," 3rd edition, 1781, pp. 25-6—viz., by extinguishing lighted candles, paper, &c., in the gas, when the smoke clings to it, rendering it visible. If gunpowder be fired in a large vessel filled with carbonic gas, the smoke, as stated by Priestley, scarcely escapes from the vessel; and, on tilting the vessel thus charged with carbonic gas and smoke, the pouring out of the gas is rendered distinctly visible even from long distances.

LECTURE V.

(25) PAGE 119.—Specular pig-iron, or spiegeleisen, contains as much as 5·5 per cent of carbon in chemical combination; when the amount of carbon sinks below 2·25 per cent, the metal ceases to be pig-iron and becomes steel. When the carbon is less than about 0·5 per cent, the metal becomes malleable iron or wrought iron.

(26) PAGE 124.—Although diamonds are usually colourless, they are occasionally found of other colours. Blue, yellow, green, and pink diamonds are known; and when of a fine colour they are more highly prized than the colourless stones.

(27) PAGE 126.—Carbonic gas is liquefied under a pressure of 36 atmospheres, at the freezing point of water. At the ordinary temperature, it requires a pressure of about 50 atmospheres to liquefy it. At a temperature of −87 C., carbonic gas is condensed to a liquid at the ordinary pressure.

(28) PAGE 126.—Solid carbonic gas thus formed is a flocculent mass, which may be exposed to the air for some

little time. A spirit thermometer immersed in it shows a temperature of $-78°$ C. If pressed on to the hand, it raises a blister, like a hot iron.

(29) PAGE 130.—By evaporating a mixture of solid carbonic gas and ether under the exhausted receiver of an air-pump, Faraday produced a temperature of $-110°$ C. By evaporating in a similar way a mixture of liquid nitrous oxide and disulphide of carbon, Natterer produced a temperature of $-140°$, the greatest degree of cold hitherto recorded.

LECTURE VI.

(30) PAGE 145.—The oxide of nitrogen here mentioned is called nitric oxide. It is a colourless gas, composed of equal equivalents of nitrogen and oxygen gases.

(31) PAGE 146.—Oil of vitriol is the name commonly applied to strong sulphuric acid. This acid has a great affinity for water; and when poured over organic bodies, such as wood or sugar, which consist chiefly of carbon, oxygen and hydrogen, it abstracts the two latter elements in the form of water, and leaves the black carbon in the separate state.

(32) PAGE 150.—Carbonous oxide, also called oxide of carbon, is a very poisonous gas. It is supposed by many that the cases of poisoning which sometimes occur when charcoal is burned in a close room, are due to the presence of a small quantity of this gas, along with the carbonic gas which is the principal product of the combustion.

(33) PAGE 156.—The mixture consists of white sugar and chlorate of potash, both finely powdered, and then mixed together. When this is touched with a drop of oil of vitriol, it takes fire, and burns with a very brilliant flame. The carbon in the sugar is the combustible body, whilst the chlorate of potash is very rich in oxygen. The drop of oil of vitriol decomposes the particles of chlorate of potash on which it falls, and causes sufficient heat to be evolved to ignite the mass.

Printed at the CHEMICAL NEWS Office, Boy Court, Ludgate Hill, E.C.